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GIRARD COLLEGE

HOUSEHOLD PHYSICS

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DOMESTIC SCIENCE TEXTS

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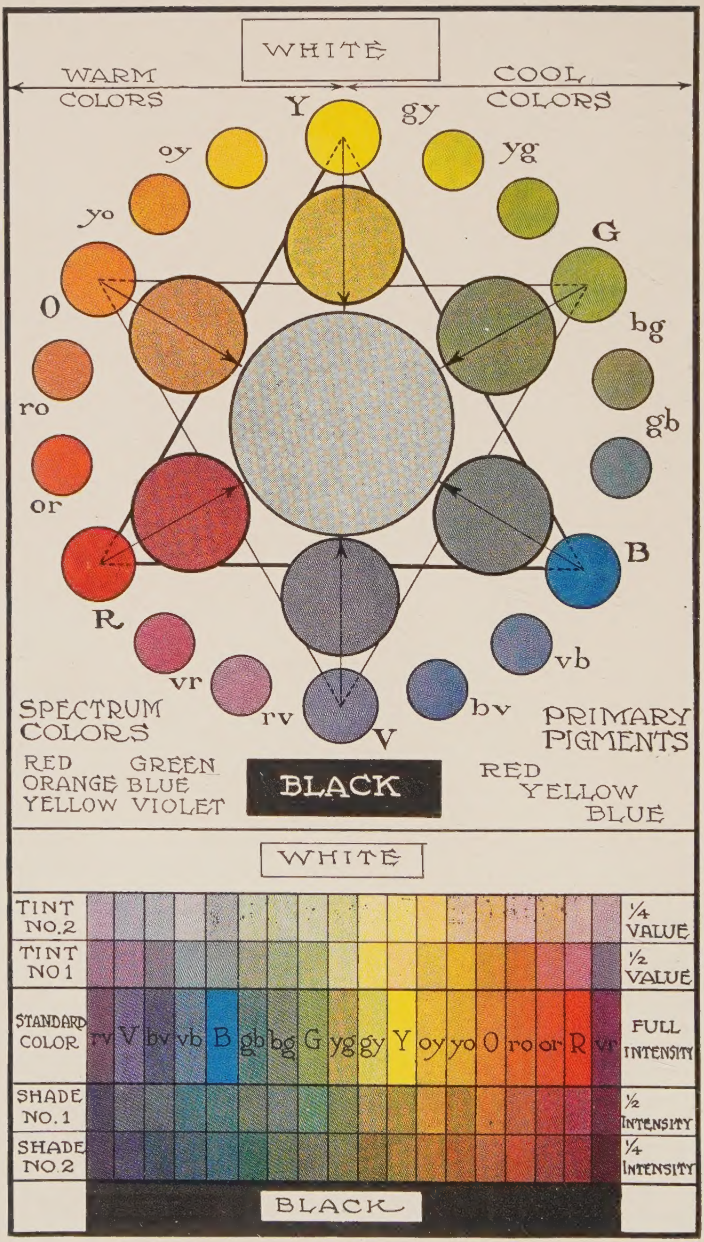

Frontispiece

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HOUSEHOLD PHYSICS

BY

WALTER G. WHITMAN

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FOREWORD

Years ago, the family gathered at dusk around a log fire, roaring in the spacious fireplace. It was the time of day for story-telling and enjoyment. If artificial light was needed, candles were used. Gas and electric lights were unknown; stoves were rarely seen. The water system was the spring, the bucket, and the boy. Nuts were cracked with a hammer and a stone. Cream was taken from the pan of milk with a "skimmer," and bread was mixed with a spoon. Contrast this picture with that of today. The fireplace — a real fireplace — has almost ceased to exist. Wood is an expensive luxury. Cream is taken from the milk in a separator. Ingenious machines crack our nuts, seed our raisins, and mix our bread, while water runs from a faucet at the sink.

It is worth your time to visit the household department of a large department store to see the washers, the sweepers, the dusters, the cookers, the coolers, the lighters and labor-savers without number, the multitude of small kitchen utensils of various machine types, the array of sanitary preparations and devices, and the collection of pest exterminators. Many of these devices are everyday necessities in your own homes; and when you are told that none of these appliances were available for your great grandmother's use — few of them for your grandmother's use — you wonder how they ever managed. In the modern home, our problems are those involved in providing proper shelter for health and comfort, water supply, plumbing, electric appliances, foods, heat, light, recreation, decoration, and necessary labor.

Count Rumford recorded a truth which is of the greatest importance to mankind when he wrote, "All the comfort, convenience, and luxuries of life are procured by the assistance of fire and heat." The value of heat lies in what it can do, not only in our homes but also in the vast industries which make

our present civilization possible. We know that our houses are warmed, our foods cooked, our clothes dried, and germs destroyed by heat. We know something of how heat is used to run engines for driving machines, to obtain metals from ores, to prepare various chemicals, and to manufacture hundreds of commercial products. Heat and light from the sun make ours a living world; for our food, coal, oil, water power, electricity, and all mechanical energy are, when traced back to their origin, products derived from the sun's energy.

The modern woman faces problems undreamed of a generation ago. Appliances and processes for the home, based upon physical laws, have multiplied with almost amazing rapidity. The girl of today cannot expect to live efficiently in this modern world, and to promote modern ideas and ideals, without a knowledge of these physical laws. This is true whether she is to become a home-maker, a business woman, or a professional woman.

This book is the result of the author's study of the problem of developing *a course in Physics for Girls*, begun some years ago in the Ethical Culture School in New York, at the suggestion of Mr. W. E. Stark, who was principal of the high school. The desire to undertake the production of a book of this type was due, also, to the influence of Professor John F. Woodhull of Teachers College, whose broad views of science and education have been so large a factor in bringing about important modifications in college entrance requirements.

The author has been materially assisted in the matter of illustrations through the courtesy of many manufacturers and publishers, among whom the following deserve special acknowledgment: The Edison Lamp Works; The General Electric Co.; The Standard Oil Company; Landers, Frary & Clark; The Singer Sewing Machine Co.; Crane Company; Westinghouse Electric and Manufacturing Co.; Bausch and Lomb; Popular Mechanics; American City; Johnson Service Co.; Johns Manville Co.; U. S. Weather Bureau: Metropolitan Ice Co., and L. J. Wing Mfg. Co.

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HOUSEHOLD SCIENCE

PHYSICS

CHAPTER I

HOW HEAT IS MEASURED

1. Need of a heat measure. We buy coal by the ton, oil by the gallon, and gas by the cubic foot. These fuels give heat, but the heat itself cannot be measured in the same units that the fuels are measured in. As a rule, we do not attempt to measure the quantity of heat in the household. It is important, however, to have a measure of heat, for the value of a ton of coal depends on the quantity of heat it can give. Large users of coal purchase coal which has a specified heat-producing value. Likewise, in many states, legislation provides that gas companies produce gas which shall not, when burned, yield less than a specified minimum amount of heat per cubic foot. We study the heat-producing values of foods in making up our diet schedules. These heat values are given in heat units and are determined by experiments in which heat is measured. We do measure *temperature* in the home and this is important in *heat* measurement, but it is only one of the factors in the measurement of heat, as we shall soon learn.

2. " Hot " and " cold." In the household, in everyday life, we constantly need to know how " hot " or " cold " the room, the oven, a vessel of water, or some other object is. This condition of the room, the oven, or the vessel of water, we speak of as its **temperature.** The temperature of a body is its condition of " heat " or " cold." Since

"cold" is only the absence of "heat," we may say that *temperature is the degree or intensity of heat.*

3. Our "feeling" unreliable in judging temperature. If we come into a room from out-of-doors on a very cold day, the room at first may seem very warm, although really too cold to remain in comfortably for a length of time. Similarly, when we first step out-of-doors from a warm room,

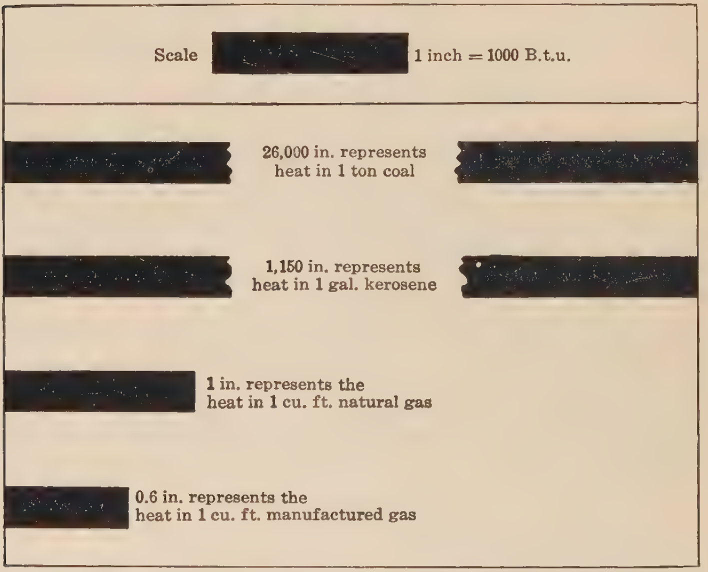


FIG. 1. — Lengths of lines required to represent the heat units in the common units of measure in which we buy these fuels. How many heat units (B.t.u.) will a ton of coal produce?

the air may seem extremely cold. It is a common experience, when two persons enter the same room, that one will say, "It is too hot here," and the other will reply, "Do you think so? It feels too cool for me." An inactive person may feel chilly in air at 68° F., while one who comes from vigorous exercise may find the same air uncomfortably warm. From such experiences in everyday life, we must infer that our sensation of heat or cold is not a very reliable indication of

the true temperature, since it is dependent on the condition of our body just before the sensation is experienced.

This we may illustrate to ourselves very readily as in Fig. 2. From the sensation of one hand, held for a time in a vessel of water at 40°, and then suddenly placed in a vessel at 70°, we should say that 70° is "very warm"; but if we test it with the other hand, which has been for a time in warm water at 110°, we should say that 70° is cold. When a piece of iron and a piece of cloth have been in a room for

Fig. 2. — Proving by experiment that "feeling" is unreliable in judging temperatures.

some time, we know that they must be at the same temperature as the air, but if we touch them both, the iron feels colder.*

* The reason that the iron feels colder than the cloth is this: The hand is warmer than the iron or the cloth and so loses heat to them, but because iron is a better conductor of heat than cloth, the heat received is carried away quickly by the iron and so more heat is taken from the hand. The piece of cloth directly under the hand gets warm, and because this heat is carried away slowly, less heat is taken from the hand. Hence the iron, because it removes more heat from the hand than the cloth does, actually makes the hand colder than the piece of cloth does.

These experiments prove the unreliability of the sense of feeling in judging temperature.

4. Thermometers. It is not now necessary to depend upon mere estimates of temperature. Very convenient and inexpensive instruments, which accurately indicate

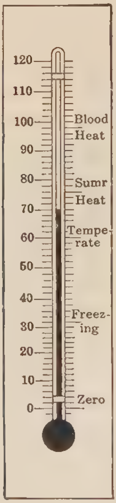


FIG. 3.

FIG. 4.

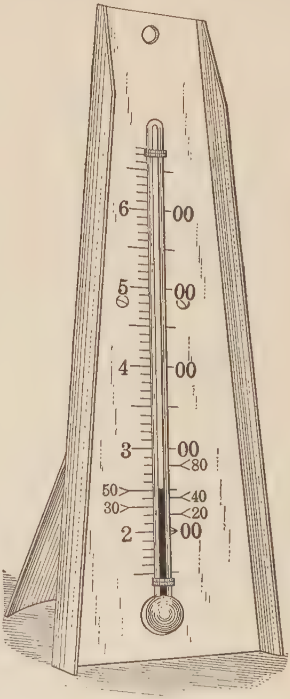


FIG. 5.

FIG. 6.

Thermometers for: living room (3); oven door (4); fireless radiator and oven (5); body temperature (6).

temperatures, may be had in various forms. Such instruments are known as *thermometers*. Thus, the thermometer shown in Fig. 3 will tell the temperature of the living room or porch and will indicate whether there is danger of a frost at night. The scientific cook of today brings the oven for

baking to a certain degree of heat, which is indicated by the oven thermometer, Fig. 4, and tells when the fireless radiator is at the proper temperature by the thermometer shown in Fig. 5. The physician carries a little thermometer, Fig. 6, with which he can tell if the temperature of the body is subnormal or if there is fever. This is such an important

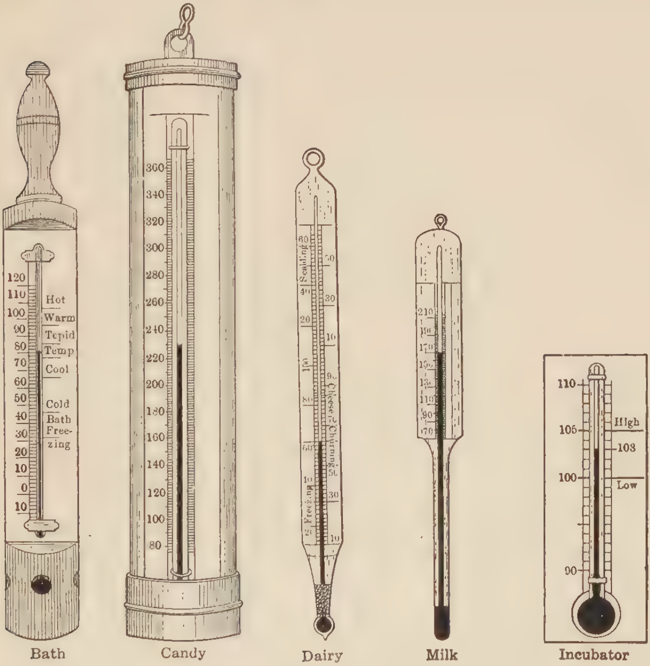


FIG. 7. — Household thermometers.

device for indicating the presence of fever that, in the interest of good health, it ought to be a part of the equipment of every household. Many other special scales are used on thermometers for special purposes, as in the milk thermometer, the bath thermometer, the candy thermometer, and the incubator thermometer. These are illustrated in Fig. 7.

5. Distinction between heat and temperature. When heat is applied to a body, the temperature of that body rises. We may easily measure the rising temperature, but *this change in temperature is not a measure of the amount of heat added.* It is really surprising how few people can tell you the difference between *heat* and *temperature,* in spite of the fact that the distinction is extremely simple. Let us illustrate this distinction by means of an analogy. Sirup, as you know, is sweet because of the sugar contained in it. Suppose we take a cupful of sirup from a gallon of sirup. We now have nearly a gallon in the can and, beside it, a cupful. Which of these has the greater quantity of sugar

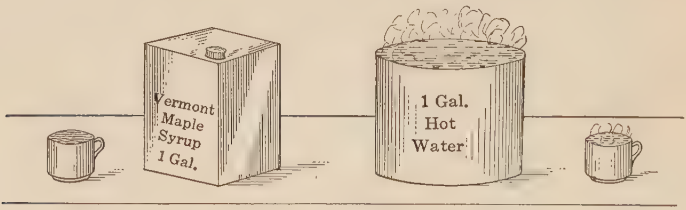


FIG. 8. — The sirup analogy.

in it? If we taste them, which will be the sweeter? You will all agree that both have the same degree of sweetness, but that the larger body has more sugar in it. Now suppose we have a gallon of boiling water and dip from it a cupful. The thermometer tells us that both have the same temperature, but do they have the same quantity of heat? If we leave them exposed to the air, the one that has the more heat will cool more slowly. An hour later, which one will be the warmer? Experience tells us that a large body of water has more heat in it than a smaller body of water at the same temperature. *Temperature,* as we have said, *indicates simply the degree of heat, but does not measure the quantity of heat.*

A red hot nail is placed on a weighed block of ice. A cup of boiling water is poured slowly upon another block of ice of equal weight. The amount of ice melted is determined in each case. In one experiment, the nail at 900° melted ½ ounce of ice. The cup of water at 212° melted 12 ounces of ice. Did the iron or the water have the higher temperature? Did the iron or the water have the greater quantity of heat?

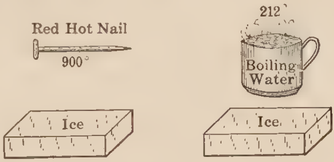


FIG. 9. — Does the body with the higher temperature have more heat?

6. The measurement of heat. It is obvious from a little thought that heat has neither dimensions nor weight; therefore, we cannot measure it as we do common material things. We cannot have a "yard of heat," a "gallon of heat," or a "pound of heat." *Heat must be measured* as electricity or light is, *by its effects.*

What is heat? We are surrounded by material bodies, as, wood, earth, metals, and water. All such bodies, which can be weighed, are known as *matter.* Certain other things which are closely associated with matter, things which we use but which are intangible, which cannot be weighed, are forms of energy and comprise heat, light, electricity, mechanical and chemical energy.

All matter is made up of very small particles called *molecules.* So small are these molecules that, in a glass of water, there are about 1,865,000,000,000,000,000,000,000 of them. These little ultra-microscopic particles are believed to be in a state of perpetual vibration, but their vibration intensity depends upon the heat. When heat is applied to a body, the molecules vibrate more rapidly; when a body loses heat, there is a loss in molecular vibration.

If we place a cupful of water and a pailful of water, both at 70° F., out-of-doors in zero weather, the water in the cup will freeze first, because it will be cooled to the freezing point first. Suppose the cupful of water and the pailful of water, both at 70° F., in vessels of the same material, are placed on the stove beside each other, which one will be warmed to 100° F. first? Experiments show that the pail of water is slower to cool and slower to warm to a given

temperature. The reason for this is that, in cooling, the larger body has more heat to give out and, in warming, the addition to it of more heat is necessary to effect the same change in temperature. A hot-water bottle containing a quart of water at 180° F., in cooling to 60° F., will give out twice as much heat as a pint of water at 180° F. in cooling to 60° F. A pound of water at 180° F., in cooling to 60° F., will give out twice as much heat as a pound of water at 120° F. in cooling to 60° F. These facts indicate *two* of the *factors* which are involved in measuring heat absorbed or evolved when water is warmed or cooled. These factors are *weight* and *change in temperature.*

Now, heat applied to water raises its temperature, and it has been observed that the *same amount of heat applied to the same weight of water always gives the same rise in temperature.* Why not make use of this in measuring heat? This is just what is done, and *water* has been chosen as the *standard substance* in heat measurement.

7. Heat units. In making a unit for measuring the quantity of heat, three things are involved: 1. A standard substance; 2. Its weight; 3. Its change in temperature.

There are two systems of heat measurement, the English and the metric. Water is the standard substance in both systems. In the English system the unit is called the **British thermal unit** (B.t.u.). It is the *quantity of heat that will raise the temperature of one pound of water* 1° *F.* The metric unit, the one commonly used in science, is the **calorie.** *This is the amount of heat that will raise the temperature of one gram of water* 1° C. As the Centigrade degree is the scientist's unit of temperature, so the gram (gm.) is his unit of mass, or weight. A larger unit, the kilogram (kg.) equals 1000 gms. One pound equals 454 gms. and one kilogram equals 2.2 pounds. The Calorie (large calorie) is the *heat required to warm one kg. of water* 1° *C.* It is equal to 1000 calories. The Calorie is approximately equivalent to the heat required to warm one pound of water

4° F. Hence the large calorie is approximately equivalent to 4 B.t.u. When the term calorie is used in connection with the energy value of food, the large calorie is meant.

PROBLEMS

1. In making coffee, how many B.t.u. are required to warm one quart (2 lbs.) of water from 50° F. to 212° F.?

2. How many calories must be given to 60 gms. of water to warm it from 20° C. to 100° C.?

3. When 4 lbs. of water in a hot-water bag are cooled from 180° to 60° F., how much heat is liberated?

4. How much heat must be taken from 50 kgs. of water to cool it from 90° C. to 30° C.?

5. When two quantities of water at different temperatures are mixed, the warmer water loses and the cooler water gains heat, until all the water is at one temperature. What will be the final temperature when 2 lbs. of water at 170° F. is mixed with 4 lbs. of water at 50° F.?

Solution. We can resolve this into two simple problems: (1) How much heat will 2 lbs. of water yield if cooled from 170° to 50°? $170 - 50 = 120°$ change of temperature. $120 \times 2 = 240$ B.t.u. (2) What change in temperature will 240 B.t.u. cause if applied to 6 lbs. of water? $240 = 6x$, or $x = 40°$ change in temperature. Therefore, $50 + 40 = 90°$ F., the final temperature of the mixture.

6. If 150 gms. of water at 90° C. are mixed with 60 gms. of water at 20° C., what will be the resulting temperature of the mixture?

7. How many gms. of milk at 5° C. must be poured into 200 gms. of coffee at 150° C. to cool it to 135° C.? Consider the quantity of heat required to change the temperature of milk and coffee the same as for water.

8. Heat capacity of different substances. In arriving at a way to measure heat we see that, with a standard substance, as water, two factors are required; *weight* and *change in temperature*. It takes 10 calories of heat to warm 1 gram of water 10° C. and 100 calories to warm 10 grams of water 10° C.

In the household we need to warm many substances besides water, and so we are led to inquire if all substances need the same amount of heat to produce the same rise in temperature. This question may easily be answered by

an experiment. We may use hot water as the source of heat and then calculate the amount of heat it gives up. For example, suppose 1 pound of water at 200° F. is poured into 1 pound of water at 100° F. and, after thoroughly stirring, the temperature of the mixture is 145° F. The fall in temperature of the hot water was 55° F. Hence 55 B.t.u. were given out by the water. The 1 pound of water, in warming from 100 to 145° F., must have absorbed 45 B.t.u. The difference between these two quantities, or 10 B.t.u., we may assume was absorbed by the containing vessel and surrounding air.

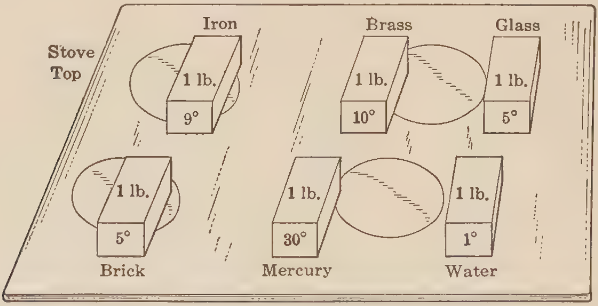


FIG. 10. — These bodies receive equal amounts of heat. Explain the different temperature changes.

Let us now melt 2 pounds of lard in a dish like that which held the water, cool it to 100° F., pour into it 1 pound of water at 200° F., and mix the two thoroughly. If lard has the same heat capacity as water, the temperature of the mixture will be 145° F. as before. What do we find? Instead of 145° F. we find the mixture temperature is 158° F. Since the lard is warmed to a higher temperature than the water was, even with less cooling of the hot water, we conclude that it does not require the same amount of heat to produce the same rise in temperature in the lard that it does in the water. In other words, the heat capacity of lard is not the same as that of water.

Let us carry the calculation further. In cooling to 158° F. the hot water gave off 42 B.t.u. Let us allow a loss of 12 B.t.u. for warming the dish and the surrounding air. This is a little more than the warm water lost when poured into the cold water, but because of the higher temperature (158° instead of 145°) there would be a greater loss of heat. After taking away 12 B.t.u., 30 B.t.u. will be left for warming the lard. Since the lard was warmed 58°, the heat it absorbed in being warmed 1° is $30 \div 58 = .51$. It therefore requires .51 B.t.u. to warm one pound of lard 1° F., while it requires 1 B.t.u. to warm one pound of water 1° F. Hence the heat capacity of lard is about one-half that of water.

And so it is with other substances. Copper holds only 0.093, and iron 0.12, as much heat as water under like conditions. Every substance has its own heat capacity. *Heat capacity* is the *third* and last *factor* necessary in order to make measurements of the quantity of heat involved in warming or cooling any substance, other than the standard substance, water.

9. Specific heat. In making a comparison of heat capacities of different substances, it is convenient to specify their ability to absorb heat in terms of the heat-absorbing power of water. The heat capacity of a unit weight of a body is its **specific heat,** which is the ratio:

$$\frac{\text{Heat absorbed by one unit weight of given substance in being warmed } 1^\circ}{\text{Heat absorbed by one unit weight of water in being warmed } 1^\circ}$$

But, since one heat unit is always required to warm one unit of water 1°, we may define *specific heat* as *the number of heat units necessary to warm one unit weight of the substance* 1°. The heat capacity of lard was found to be 0.51 that of water; hence the specific heat of lard is 0.51.

It requires 0.51 B.t.u. to warm one pound of lard 1° F., and it takes 0.51 calories to warm one gram of lard 1° C. That amount of heat which is gained by a body in being warmed,

is lost when the body is cooled through the same change in temperature. The specific heat of water is 1. It takes 100 calories to warm 25 grams of water 4° C., and when 25 grams of water are cooled 4° C., 100 calories of heat are liberated.

The numerical value of the specific heat of a substance may easily be determined experimentally. Water is commonly used as a convenient substance for measuring the quantity of heat. This method, known as the **method of mixtures,** is as follows: We may wish to find the specific heat of aluminum. Two hundred grams of aluminum are warmed to 300° C., and immersed in 1000 grams of water at zero. The temperature of the water rises to 12° C. The water gained $1000 \times 12 = 12{,}000$ calories. This heat was lost by the aluminum in being cooled 288° C. One gram of aluminum, in cooling one degree, must have lost $\frac{12{,}000}{200 \times 288}$, or 0.21 calories; hence the specific heat of aluminum is 0.21. In making an exact determination a small allowance would be made for the heat absorbed by the containing vessel.

TABLE I

SPECIFIC HEATS

Liquids

Ammonia (liquid)	1.012	Mercury	.033
Alcohol (ethyl)	.615	Milk	.940
Methanol (methyl alcohol)	.590	Olive oil	.309
Light cream	.950	Petroleum	.460
Glycerine	.550	Turpentine	.459
Lard (melted)	.510	Water	1.000

Gases

Air	.238	Hydrogen	3.410
Ammonia (gas)	.508	Nitrogen	.244
Carbon dioxide	.247	Oxygen	.217
Carbon monoxide	.242	Steam	.480

Solids

Aluminum	.212	Limestone (or marble)	.216
Apples	.910	Nickel	.100
Beef (lean)	.770	Plaster	.200
Brass	.094	Platinum	.032
Brick	.195	Potato	.800
Celery	.960	Salt	.170
Charcoal	.242	Silver	.056
Coal	.204	Soapstone	.210
Copper	.093	Steel	.120
Eggs	.790	Stone (general)	.210
Glass	.190	Veal	.700
Human body	.830	Wood: Birch	.480
Iron (wrought)	.113	Oak	.570
Iron (cast)	.130	Pine	.467
Lead	.031	Zinc	.093

10. How specific heat is determined. When water at one temperature is mixed with a substance at a different temperature, the warmer body loses heat and the cooler gains heat. Except for the small amount of heat absorbed by the containing vessel, called a **calorimeter,** the heat lost by the warm body is taken by the cool body, and by a simple calculation the specific heat of the body is obtained. This is the *method of mixtures* and was previously described for finding the specific heat of melted lard and of aluminum.

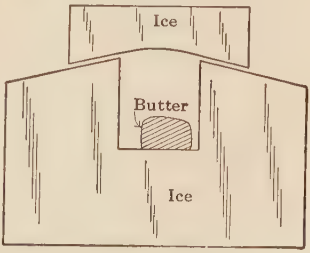


FIG. 11. — An ice calorimeter.

If we wish to determine the specific heat of the solid lard, butter, or other substance which would melt in hot water, the **ice calorimeter,** Fig. 11, can be used. A cavity is made in a block of ice, the substance whose specific heat is to be determined has its temperature taken, and, after the cavity is wiped dry, is dropped into it and quickly covered with another block of ice which fits tightly over it. To melt one gram of ice requires 80 calories. Hence, from the amount of ice melted,

determined by absorbing the water on a piece of cotton, and weighing it, it is possible to calculate how much heat was given up, and so to find the specific heat.

Another method of finding the heat liberated in melting ice is by use of the **Bunsen ice calorimeter,** which is shown in Fig. 12. First, a part of the water in chamber *A* is frozen by a freezing mixture in *B*. The freezing mixture is removed and the substance whose specific heat is to be determined is heated and placed in *B*. As contraction occurs during the melting of ice, the mercury in the indicator tube is drawn back in proportion to the amount of ice melted. The amount of ice melted gives data for calculating the heat lost by the body, and so the specific heat can be obtained.

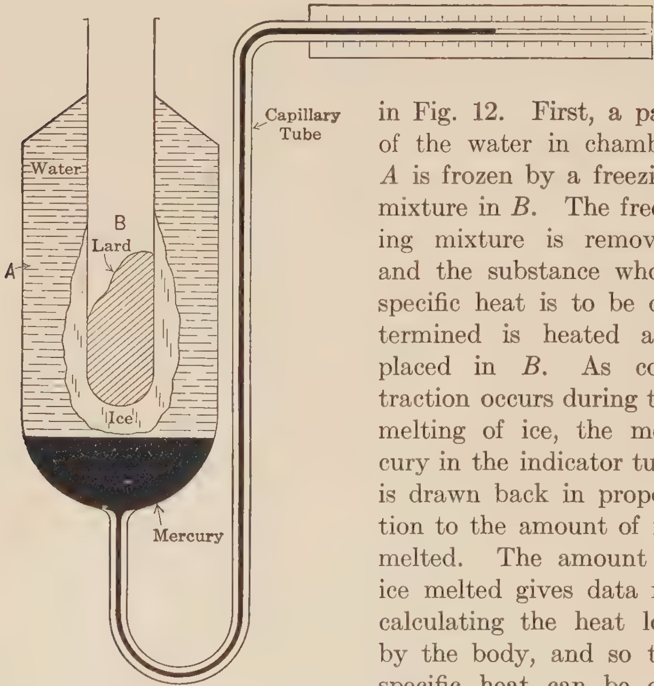


FIG. 12. — Bunsen's ice calorimeter.

Problem: How much heat will be required to warm 200 gms. of aluminum from 10° C. to 100° C.?

Solution: The specific heat of aluminum is .212.

Hence it takes .212 calorie to warm 1 gm. of aluminum 1° C.

$200 \times .212 = 42.4$ calories to warm 200 gms. 1° C.

And $42.4 \times 90 = 3816$ calories to warm 200 gms. aluminum from 10° C. to 100° C.

If we had 200 gms. of aluminum at 100° C., it would give up 3816 calories in cooling from 100° to 10°. From this we may deduce this formula:

H	=	W	×	Sp. H.	×	Ch. T.
Heat given out or heat absorbed	=	Weight	×	Specific heat	×	Change in temperature

PROBLEMS

1. A 7-lb. flatiron is heated to 490° F How much heat will it lose in cooling to 300° F.?

2. How much heat is required to warm 2 lbs. of lead from room temperature (70° F.) to its melting point (625° F.)

3. One quart (2 lbs.) of boiling water (212° F.) is poured into an iron kettle weighing 6 lbs. and having a temperature of 40° F. How much will the water be cooled? Suggestion: Resolve this into four simpler problems as follows:

(1) How much heat will the water give up if cooled to 40° F.?

(2) How much heat is required to warm the mixture, consisting of 2 lbs. water and 6 lbs. iron, 1° F.?

(3) How many degrees will this mixture be warmed by the available heat from the hot water?

(4) What final temperature will this change in temperature give?

4. An egg weighing 260 gms. and having a specific heat of 0.6, is taken from the refrigerator at 12° C. and dropped immediately into 100 gms. of water at the boiling temperature (100° C.). To what temperature will the water be cooled?

5. Which is the best bed warmer, a hot-water bottle containing 1 quart (2 lbs.) of water at 200° F., a 7-lb. flatiron at 200° F., or a brick weighing 5 lbs. heated to 200° F.?

260 × .6 × (t − 12) ×1×

156 t

11. The fuel value of foods and fuels. The amount of heat given out during the combustion of coal or of a piece of bread can readily be determined with an apparatus known as the **bomb calorimeter,** Fig. 13. This has an inner chamber where the wood or fuel can be placed with compressed oxygen and then set on fire by means of an electric current.

This chamber is surrounded by water which absorbs the heat given up during combustion. From the weight of water and its rise in temperature, it is a simple matter to find how much heat resulted from combustion. It is by

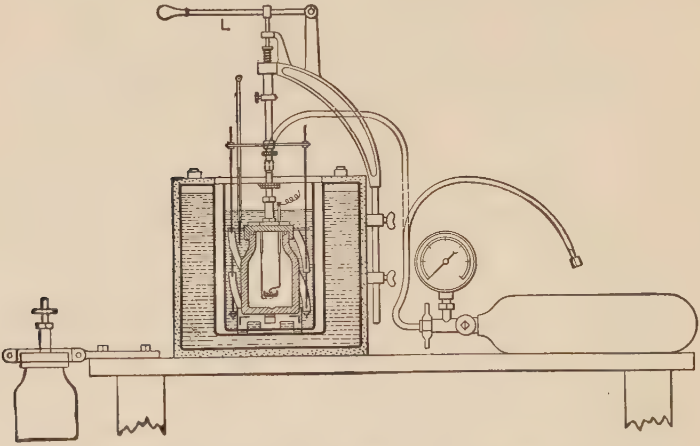


Fig. 13. — Bomb calorimeter. Oxygen for combustion is supplied from tank at right.

this method that the fuel values of various foods and fuels are determined.

12. Specific heat in everyday life. If equal quantities of heat are given to equal weights of water and of earth, the earth, because of its lower specific heat, will be warmed to a higher temperature, Fig. 14. For this reason, the land gets warmer than the water of the ocean or lake when under the direct rays of the sun. This is important in modifying climate, as it causes winds to blow from the cooler water in hot weather, and the water gives out much of its stored heat in cold weather, thus moderating the climate of nearby land.

You will readily understand that substances with high specific heat can store up more heat during a given change

in temperature than can substances of low specific heat. Milk, tomatoes, and oranges will cause more ice to melt in the refrigerator than equal weights of cheese, butter, and meat, for the reason that milk, tomatoes, and oranges have higher specific heats than cheese, butter and meat. Other

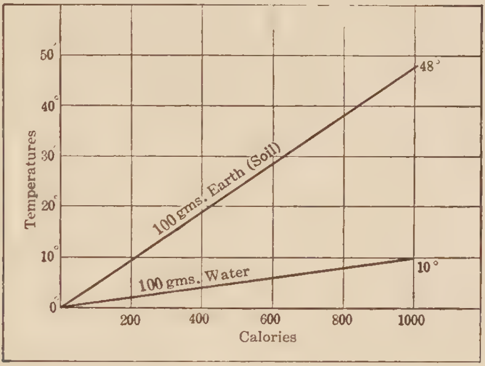


FIG. 14. — The same amount of heat that warms 100 grams of water 10° will warm 100 grams of earth nearly 50°.

important applications of specific heat are found in building materials, house heating, fireless cookers, and many other things which are in common use in the home.

QUESTIONS

1. Bread and the pan in which it is baked are at the same temperature when taken from the oven, yet you might get a severe burn by touching the metal pan, while no harm would result from touching the bread. Why is this so?

2. The walls of the oven and the air in it are at the same temperature. Some people test the temperature of the oven by holding the hand in it for a moment, but if they touch the wall of the oven they are badly burned. Explain.

SUMMARY OF CHAPTER I

1. Temperature is the degree of heat in a body.

2. Cold is the absence of heat.

3. One important effect of heat is that it causes a rise in temperature.

4. The sense of feeling is unreliable as a means of judging temperatures.

5. Thermometers are instruments for indicating temperatures.

6. Temperature is not the same as heat.

7. Temperature is one of three factors essential in determining the quantity of heat.

8. A British thermal unit (B.t.u.) is the quantity of heat required to warm one pound of water 1° F.

9. A calorie is the quantity of heat required to warm one gram of water 1° C.

10. When a substance cools through any number of degrees, it liberates the same quantity of heat that would be required to warm it to its original temperature again.

11. Different substances have different heat capacities.

12. Specific heat is the quantity of heat required to warm a unit weight of a substance 1°.

13. Water, the standard substance for heat measurements, has a specific heat of 1.

14. Three essential factors in calculating the quantity of heat a body gains in being warmed, or which it loses in being cooled, are: weight, change in temperature, and specific heat.

Heat = Weight × Change in temp. × Specific heat.

15. Specific heat may be determined by the method of mixtures or by means of the ice calorimeter.

16. The bomb calorimeter is used in finding the heat of combustion of fuel and foods.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. Buying coal by the calorie.
2. The nutrition calorimeter and its value.
3. Test two flatirons for heat capacities.
4. Find the specific heat of butter by the ice calorimeter.

REFERENCE BOOKS

LYNDE. *Physics of the Household.* The Macmillan Company.
RANDALL. *Heat.* John Wiley & Sons, Inc.
SMITH. *Elements of Applied Physics.* McGraw-Hill Book Company.

CHAPTER II

HOW WE MAKE USE OF EXPANSION

13. Knowledge of expansion is useful in the home. With one effect of heat — *rise in temperature* — we are familiar. A second effect of heat — *change in size* — is of great importance and needs now to be considered. When a body increases in size, it *expands;* when it decreases in size, it *contracts.*

When the cover on the fruit jar sticks, or a glass stopper refuses to be withdrawn from a bottle, if the cover or the neck of the bottle is dipped into hot water for a moment, the jar or bottle may often be opened with ease. In making household repairs it is desired at times to remove a rusted screw or nut, but the use of the screwdriver or wrench fails to give results. The ingenious household mechanic will place a hot iron against the head of the screw or will heat the nut, which can then be removed in the usual way. If nursing bottles are filled *full* of cold milk and put into the pasteurizing chamber, some of the milk will overflow when it is heated. Sometimes in hot weather we find the corks of bottles mysteriously removed. This is often caused by the heated gas inside pushing them out. In a similar way, gas bubbles in bread and cake increase in size when heated and make the bread and cake light and porous. When

FIG. 15. — A fruit jar cover is loosened by holding it in hot water.

the stove top gets red hot frequently, some of the parts are lengthened and put under too great strain, with the result that they warp and become permanently bent out of normal shape. Boiling water will crack a cold glass dish, and a drop of cold water will shatter a hot lamp chimney. Strong heat applied quickly to an enameled-ware dish will cause the enamel to expand and pieces of it to chip off before the iron beneath has had time to expand an equal amount. Unless a clock or watch has some expansion compensating device, it will need adjustment when changing from winter to summer temperatures, in order to keep correct time. The cement walk may buckle in hot weather,

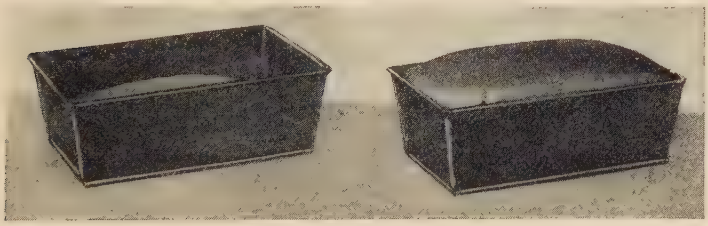


Fig. 16. — Bread is made "light" by the production of gas in it and by the expansion of the gas.

while cracks are made in ice and in the frozen ground in extremely cold weather. This effect of heat — *change in size* — is also made use of in the thermometer and the thermostat. Expansion must be considered in industries, as when wires are sealed into glass in making electric lamps. The value of expansion in nature, as an agent in making soil, is very great. Even the circulation of air and water in our systems of house heating, as well as the winds and storms outside our homes, depend indirectly upon this very important effect of heat.

14. Expansion of solids demonstrated. Suspend one end of a No. 14 copper wire, 2 to 3 feet long, from a support, as in Fig. 17. Make a loop (L) near the other end of the

wire, and bend the wire so that it extends about 2 or 3 inches horizontally, as *B*. Attach a heavy weight to the loop in order to hold the wire straight. Let the end *B* rest on the short arm of a light lever at *A*. The lever may be made of folded paper turning upon a pin placed into a support at *C*. Mark the height of the long arm of the lever by placing some object there, as *D*. Heat the copper wire by moving the flame up and down the length of the wire. If the wire increases in length, the weight is allowed to go lower, carrying *B* with it. As *B* presses down on *A*, by the principle of the see-saw, the other end of the lever will be lifted along *D*. What is the result as the wire is heated? Do you observe that after the wire cools the lever returns to its original position?

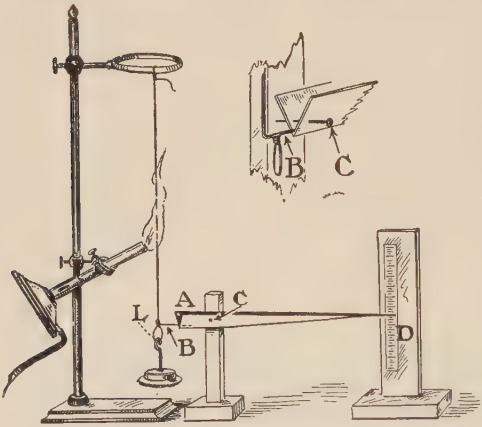


FIG. 17. — The pointer rises on scale *D* when the wire is heated. Why?

The lengthening of objects by heating is even more strikingly shown by using 15 feet of No. 26 iron wire held horizontally between two supports *A* and *B*, as in Fig. 18, and passing an electric current from the 115-volt lighting circuit through it. This current will warm the entire wire uni-

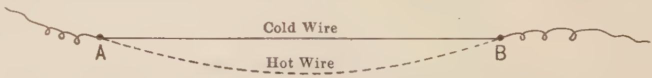


FIG. 18. — Sagging of an iron wire when heated by passing a strong electric current through it.

formly, and as a result, the wire will lengthen and sag about 6 inches at the middle point. When the current is cut off, the wire cools and returns to its original position.

We have now seen that two substances, copper and iron, *increase in length* when heated. They also *increase in diameter in the same ratio.* We have not tried to show whether these two metals expand the same amount for the same rise in temperature, but careful experiments have shown that they do not expand alike. The variation of a few common substances in ability to expand is shown in Tables II and III on pages 29 and 30.

Explanation of expansion. Recall the theory of the constitution of matter, that all substances are composed of tiny particles — molecules — which are separated by spaces probably larger than the diameter of the molecules themselves. Also recall that heat is the motion of these molecules within very limited spaces, but that each molecule may move through the space surrounding it and at frequent intervals may bump into neighboring molecules. If the molecules receive more heat energy, they vibrate with greater energy, and when they meet, they strike harder blows. As a result they are pushed a little further apart. This causes an increase in size, or expansion.

15. Expansion of liquids. Fit two test tubes of the same size with rubber corks, each having a glass tube, 10 inches long, inserted in it as in Fig. 19. Fill one tube with colored water. Close with the stopper, pressing it in until water stands about 2 inches above the stopper. Fill the other tube with colored kerosene. Close it and press in the stopper until the kerosene stands at the same level above the

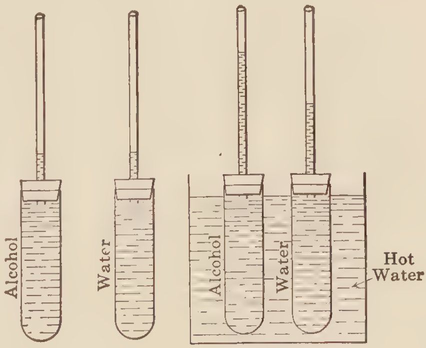


Fig. 19. — Alcohol expands more than water does under the same change in temperature.

stopper as the water does in the other tube. Immerse these two test tubes in a beaker of hot water. What is the result? Do the two liquids increase equally in volume for the same rise in temperature? If alcohol and gasoline are used, results parallel with those just seen will be obtained.

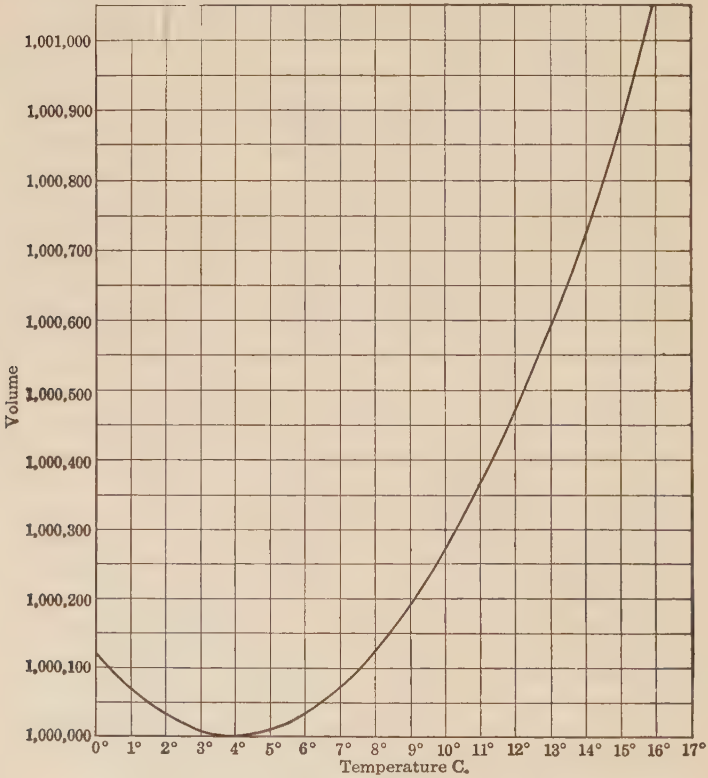


FIG. 20. — Expansion curve for water.

It is thus easy to demonstrate that *liquids expand when heated and contract when cooled,* and also that the *amount* of expansion for a given change in temperature *depends upon the liquid* used, being greater for alcohol, kerosene and gasoline than it is for water.

There is often considerable variation in the expansion of the same liquid at different temperatures. This fact, illustrated for water, is shown in Fig. 20. Here, unexpectedly, we find that water contracts when heated from 32° F. to about 39° F. (0° C. to 4° C.), and then expands, though not uniformly, at higher temperatures.

16. Will gases expand? After seeing that some solids and liquids expand when heated, we may wonder if gases expand similarly. Experiment will show us. A large glass bulb, with a long, slender tube attached, is held with the open end of the tube under water, as in Fig. 21. Since the

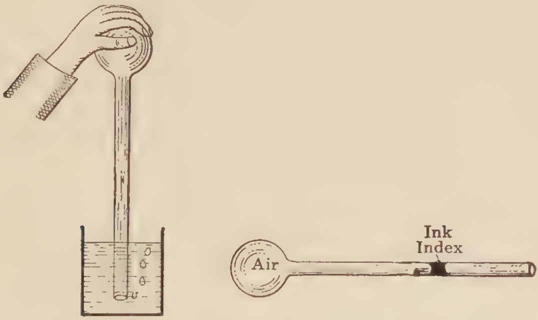


FIG. 21. — Expansion and contraction of a gas under changes of temperature.

bulb and tube at the start are full of air, if the air expands upon being heated it must escape through the water and we shall see the bubbles. Warm the bulb with the palm of the hand. The escaping bubbles prove that the air expands when heated. If we use ink instead of water and let the air cool in the bulb after heating, we find that the ink follows the contracting air up the tube. If we warm the air again, we see that, as it expands, it exerts greater pressure and pushes the ink down the tube. As the air cools and contracts its pressure is less, and the ink rises again. It has been found that *all gases expand and contract to just the same extent as air* does under the same changes of temperature.

In cooking, air is frequently used to secure lightness. For example, air beaten into pie crust expands in baking. If *cold* air, rather than *warm* air, is beaten in, as much as a 5 per cent increase in volume may be secured.

17. Expansion changes the density. Density means the *weight of a unit volume* of a substance. A flask full of air at room temperature has a certain weight. If, after the air is heated, the flask full of air weighs less than it did before, the density of the contained air is less, but if it weighs more, the density is greater. Let us see what effect heat has upon the density of air. Referring to Fig. 22, *A* is a liter

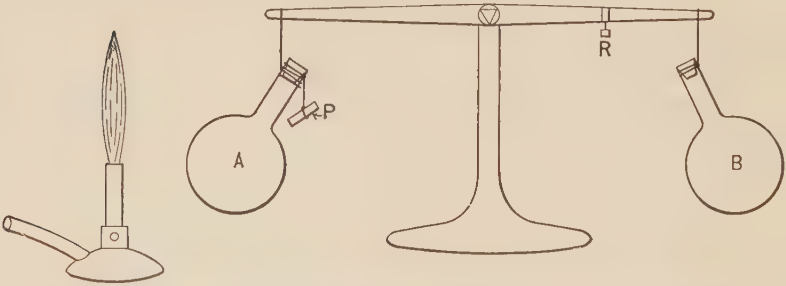


FIG. 22. — Apparatus used in showing that cold air is heavier than warm air.

flask having a one-hole rubber stopper. A glass plug *P* is used to close the hole in the stopper. Suspend the flask *A*, with the stopper and plug, from one arm of a balance and exactly counter-balance this with another flask *B* and a rider *R*. Heat the flask *A* quite strongly with a moving gas flame. While the flask is hot, close it by inserting the plug *P* into the stopper. When the balance arm is released, does *A* rise or sink? You probably know that the heat causes some of the air to escape, and if the flask is closed no air can go back as the flask cools; but the flask still remains full of air. Since its weight is less than before, the *density* of the air *is less*. Hot water is less dense than cold water;

in fact, everything that expands when heated is less dense when hot than when cold.

18. Convection currents the result of expansion. One of the most important results of expansion is the creation of *convection currents.* Convection currents always occur when *a part* of a body of liquid or gas changes in density. We can easily make these currents visible. Let us drop a few crystals of potassium permanganate down the side of a beaker of water and place a Bunsen-burner flame directly under the crystals as in Fig. 23. The crystals slowly dissolve, and color the water. If the water about the crystals moves, we can see this movement because all the water passing over the crystals becomes colored. Immediately following the application of heat we see currents of water rising from the place where heat is applied. This stream of rising water broadens, moves across the top, and then sinks, as suggested by the arrows. After a time the colored water is thoroughly diffused, and since the colored water is the heated water, we may reason that the water in the entire vessel eventually becomes hot, chiefly through the movement of these convection currents.

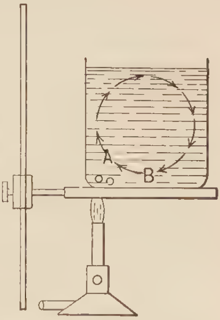


FIG. 23. — Convection currents in water.

Since water expands when heated, a cubic inch of hot water weighs less than a cubic inch of cold water. **Weight,** as you doubtless know, is the measure of the force of gravity, or the force that is pulling all objects on the earth toward the center of the earth. If you compare the weight of a cubic inch of water at *A* —warm, expanded, and less dense water — with that of a cubic inch of water at *B*, which is cold and not expanded, it is apparent that the water at *B* is heavier than that at *A*. In other words, *B* has *more weight* than *A*, and will accordingly be pulled toward the earth with greater force. As a result, the cold water takes the lowest

place in the beaker, and as it flows in under the warm water at A, it lifts or pushes the latter upward. Then the water which has lifted A in turn becomes heated, and other cold water comes in and pushes it upward. This process continues without interruption until all the water is of the same temperature. The ascending hot water mingles with colder water, which is warmed by it.

The importance in nature of the peculiar expansion of water shown in Figure 20 may now be understood. If the expansion of water did not take place in this manner, when a body of water cooled on the surface, the colder surface water would continue to be denser until 32° F. (0° C.) was reached. In this event the surface water would continue to sink until the body of water was at 32° F. throughout, and the water might freeze solid from top to bottom. What actually happens, however, is that, after the water has cooled to 39° F. (4° C.), further cooling causes no contraction and therefore no increase in density, and the layer of colder water remains on top to form a sheet of surface ice.

For the reasons discussed above for water, convection currents occur in the air. We are dependent upon convection currents for natural ventilation, for heating our rooms and cooling our refrigerators, for winds, storms, and other climatic conditions.

19. Coefficient of expansion. *The coefficient of linear expansion* is a technical term used by the scientist to indicate *that fraction of its length that any solid body expands for a rise in temperature of* 1°. This may be given for the common Fahrenheit degree or for the Centigrade degree used by the scientists. For a liquid or a gas, the coefficient is given as *the fraction of its volume* that the liquid or gas increases *for* 1° *rise in temperature.* There is some variation in the rate of expansion at different temperatures, hence the figures found in a table of coefficients must be considered in general only as approximately correct.

By using these coefficients it is possible to calculate the change in length or volume of various bodies for a given rise in temperature. For example: suppose an iron pipe runs along one side of the school building for a distance of 100 feet. This pipe may vary in temperature from 0° Centigrade when no steam is on, to 110° Centigrade when steam is on under pressure. What will be the change in the length of the pipe? The rise in temperature is 110° C. Iron expands 0.000011 linear units per Centigrade degree for each unit of length. The total expansion is then $100 \times 110 \times 0.000011 = 0.121$ feet. Changed to inches, this makes 0.121×12 or 1.452 inches.

Suppose the volume of the bubbles of gas in a loaf of bread, just as it is put into the oven, amounts to 10 cubic inches, and that the temperature of the loaf is 70° F. and goes to 430° F. in the oven. What will be the approximate increase in volume? The change in temperature is $430 - 70 = 360°$ F. The coefficient of expansion of a gas is 0.002. The increase in volume will be $10 \times 430 \times 0.002 = 7.2$ cubic inches.

Table II

COEFFICIENTS OF LINEAR EXPANSION

	For 1 degree C.	For 1 degree F.
Aluminum	0.000023	0.000013
Tin	0.000022	0.000012
Silver	0.000019	0.00001
Brass	0.000018	0.00001
Copper	0.000018	0.00001
Steel	0.000013	0.000007
Cast iron	0.000011	0.000006
Platinum	0.000009	0.000005
Glass	0.000009	0.000005
Glass — Pyrex	0.000003	0.0000016
Nickel-steel alloy	0.000009	0.000005
Quartz	0.0000005	0.0000003

TABLE III

COEFFICIENTS OF CUBICAL EXPANSION OF LIQUIDS AND GASES

Alcohol	0.0012	0.00066
Ether	0.0015	0.0008
Petroleum	0.0009	0.0005
Mercury	0.00018	0.0001
Water	0.00043	0.00024
All gases	0.00366	0.002

PROBLEMS

1. A cubic foot of air at 0° C. is warmed to 273° C. What will be its new volume if there is no change in pressure?

The increase in volume = V. (original vol.) × coef. of exp. × change in temp.

Increase in volume = 1 × 0.00366 × 273.

Increase in volume = 0.999 + or practically 1 cubic foot.

New volume = original volume + increase.

New volume = 1 + 1 = 2 cubic feet.

Hence, when a gas is warmed 273° C. its volume is doubled.

2. (a) Compare the contractions of 6-inch lengths of glass and of quartz tubing when heated to 382° F. and then cooled to the temperature of ice water. (32° F.)

(b) Do these results help to explain why glass is shattered, while the quartz is unharmed, when suddenly cooled?

3. In a thermometer of a given size of bulb and a given size of bore in stem, which liquid, mercury or alcohol, will rise a greater distance in the stem per degree increase in temperature? Explain how you reached this conclusion.

4. Compare the increase in volume of mercury with that of alcohol, in thermometers whose bulbs hold 1 c.c. each, when the temperature changes 80° C.

5. Which will increase in size the more, 1 cubic foot of air or 1 cubic foot of illuminating gas, if warmed from 32° F. to 80° F.? Explain.

6. The opposite walls of a building bulged outwards several inches. Workmen passed a steel bar through both walls, heated the bar to 600° F. with torches, and fastened the ends securely to the walls, which were 60 feet apart. The bar cooled to 50° F. and drew the walls in. How much were they drawn in?

7. If air enters the furnace at −10° F. and leaves it at 100° F., what will be the increase in volume of 1000 cubic feet of cold air in passing through the furnace?

20. The need for knowing the coefficient of expansion. If a bridge builder has to build a continuous steel bridge a mile long, he must allow about 5 feet of space for its change in length during the year. He calculates this about as follows: the length is 5280 feet; each foot expands 0.000007 for each degree rise in temperature; from winter to summer the temperature may vary 140° F. Then the expansion would be:

$$5280 \times .000007 \times 140 = 5.1 \text{ feet}$$

In a similar way, when steel rails are laid exposed to the air, a space is left to allow for expansion. Rails laid in the street, well surrounded, except for the top surface, with earth, cement, or cobblestones and tar, are not subjected to such extremes of temperature, and consequently do not tend to expand so much as the more exposed rails. Such rails are frequently welded together so that there is a continuous rail several miles long.

FIG. 24.— Wires are sealed in the glass at the top of the glass stem.

In many electrical appliances, including the common incandescent lamp, it is necessary to seal a wire into the glass, as shown in Fig. 24, to make an air-tight joint. Can copper wire be used? The coefficient of expansion of copper is .000018; that of glass is .000009; copper expands twice as much as glass for the same change in temperature. Such unequal expansion would soon cause the glass to crack. It is observed that platinum and some nickel steels have the same coefficient of expansion as glass. Trial has proved that either of these can be used satisfactorily to pass an electrical current through glass. In practice, however, it is found best to use a nickel iron core with an expansion coefficient less than that of glass surrounded by a copper sleeve. This wire, known as "Dumet,"

expands more than nickel iron, but less than copper and slightly less than glass.

In heating systems in large buildings, where long pipes for steam or hot water are used, allowance must be made for pipe movement, or else expansion valves must be inserted at intervals. In order to have a free movement of air through the heating chambers of heating devices, it is important to know how much the air will expand. With this knowledge, the intake and outlet ducts can be made of proper sizes. The engineer, the mechanic, and the manufacturer make frequent use of the coefficient of expansion. They have made the calculations and produced equipment for the home, which we use without a thought of what has been done for us.

QUESTIONS

1. In tuning a piano, the tension of a wire is increased to raise its pitch. What will be the effect of an increase in temperature on the pitch of a piano?

2. Why should a thick piece of glass crack more quickly than iron when suddenly heated? Give another reason besides brittleness.

SUMMARY

1. Two important effects of heat are change in temperature and change in size (expansion).

2. Knowledge of expansion is helpful in many ways in the home.

3. Nearly all substances expand when heated and contract when cooled.

4. Expansion causes a decrease in density.

5. Convection currents result from a change in density caused by expansion. The denser cold liquid or gas, pulled by gravity, flows in under the lighter warm liquid or gas and lifts it. This explains why "hot air rises."

6. The coefficient of linear expansion is that fraction of a unit length that a given substance expands for a rise

in temperature of one degree. This will not be the same for Fahrenheit as it is for Centigrade degrees.

7. The coefficient of cubical expansion is that fraction of a unit volume that a given substance expands for a rise in temperature of one degree. This may vary for liquids, but all gases have the same coefficient of cubical expansion. The coefficient of cubical expansion of solids is three times the coefficient of linear expansion.

8. The engineer, mechanic, and manufacturer have to use the coefficients of expansion in their calculations, before making certain constructions and devices for our use and comfort.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. Some interesting results of expansion and contraction of bodies in nature.
2. How the engineer must take expansion into account.
3. Find out at what temperature hot water will crack thick glass.
4. Devise an experiment to measure the expansion of air when heated.

REFERENCE BOOKS

Dull. *Essentials of Modern Physics.* Henry Holt and Company.
Randall. *Heat.* John Wiley & Sons, Inc.
Smith. *Elements of Applied Physics.* McGraw-Hill Book Company.

CHAPTER III

THERMOMETER

21. Early development of the thermometer. Perhaps you read a thermometer one or more times a day, but do you ever stop to think of the investigation, the thought, and the skill that has brought this simple but essential instrument into its present state of perfection? History records that in 1592, just one hundred years after Columbus discovered America, Galileo, that Italian scientist who also made the first telescope, invented an instrument to show changes in temperature. This device, Fig. 25, consisted of a hollow glass bulb fitted to a glass tube about 16 inches in length. The air in the bulb was first heated until some of it had escaped, with the result that when it was cooled, after the open end of the tube had been placed in water, the water rose part way up the tube. A rise in temperature would then cause the liquid to fall, and a drop in temperature would cause it to rise. By placing a scale back of the tube, changes in temperature could be observed just as we observe changes with our present-day thermometer. Since the action here is due to the expansion or contraction of air, this device is called an **air thermometer.** Air thermometers are in use today for some purposes. It was not long before the expansion of liquids was used in thermometers, but for more than a hundred years very little progress in accuracy or in standardizing a scale was made.

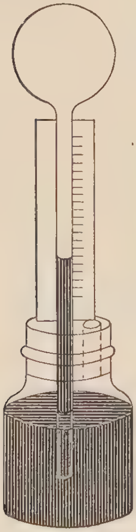
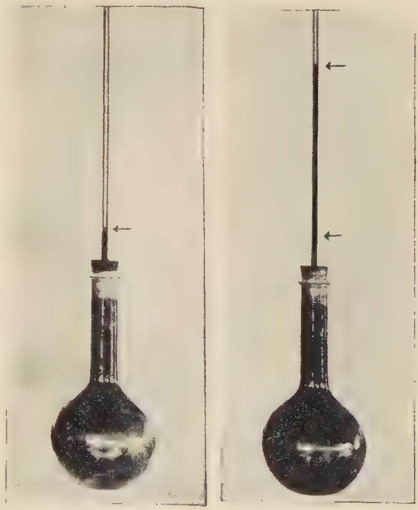


FIG. 25. — Air thermometer, first used by Galileo.

22. How thermometers indicate temperature. Two effects of heat — *a rise in temperature* and *expansion* — are closely associated, and it is the dependence of one of these upon the other that makes it possible to determine one by measuring the other. In general, as the temperature of a body rises the body expands. Any substance which expands uniformly with an increase in temperature may be used to indicate temperature. Let us illustrate the action of a thermometer by means of a flask full of water, with a stopper and a glass tube rising 10 inches above it, as shown in Fig. 26. If colored water is used, it will be more easily seen. As the stopper is pressed in, see that the liquid stands about 2 inches above the stopper in the tube. Fasten a piece of white paper back of the tube, and mark the level of the water. If, when the flask is heated, it grows larger, what will happen? Will the water rise or fall in the tube? You are right, it will fall. Now watch carefully as the flask is set in a basin of hot water (180° F.). As you expected, the water first drops in the tube, proving that the flask was made larger; but look again, and see what is happening. The water now rises in the tube even higher than it stood originally. Does the flask grow smaller? No. Then what is the



A B

FIG. 26. — Expansion of water. *A*. At room temperature. *B*. Result of placing the flask in hot water for one minute.

explanation? Could expansion give the effect we have just seen? We see that it could, if we but note that the water must expand more than the glass does. The glass increased in size first because all the heat the water receives must come through the glass. Action similar to this takes place in the common mercury thermometer. The *apparent expansion* in a mercury thermometer is but five-sixths of the *real expansion*. This is because of the increase in size of the thermometer bulb and tube. By agreeing on some unit, and preparing a scale for measuring the apparent increase in size, it is possible to obtain an accurate measurement of temperature.

23. Liquids for thermometer fillers. We have just used water in our demonstration thermometer, but there are serious objections to its use in a practical thermometer. It freezes at a much higher temperature than we have in our cold winters, and it boils at a lower temperature than we use for baking or candy making. Another property that makes water unsuitable for measuring temperature is its irregular expansion. Its coefficient of cubical expansion varies from 0.000053 to 0.000059, depending upon its temperature. Study of the expansion curve for water in Fig. 20, also shows that in warming from 0° C. to 4° C. (32° F. to 39° F.) water contracts, and then expands upon a further increase in temperature. Its value at 2° C. would be practically the same as at 6° C. In fact, for all temperatures below 9° C. there would be uncertainty in regard to what the reading indicated.

Two liquids, mercury and alcohol, have proved their usefulness in the thermometer. Mercury is best adapted for use in our common thermometers, for several reasons. It expands more uniformly at different temperatures than most liquids, Fig. 27, and it has an extensive range between its freezing point (−39° F.) and its boiling point (495° F.). It is a metal, and so a good conductor of heat. In being warmed 33 degrees, it absorbs only as much heat as the

same weight of water in being warmed one degree. For these reasons it responds quickly to changes in temperature. Mercury is opaque and therefore easily visible.

The blue and red liquids in common thermometers are usually alcohol. The coefficient of expansion of alcohol increases with a rise in temperature, and for this reason alcohol thermometers are usually less accurate than mercury thermometers. Since alcohol boils below the boiling temperature of water, it is not suitable for thermometers used in measuring the temperatures involved in many household processes. It does have a distinct advantage over mercury, however, for low temperatures. In our northern states mercury freezes in winter, but nowhere on the earth does natural cold ever reach the freezing point of alcohol.

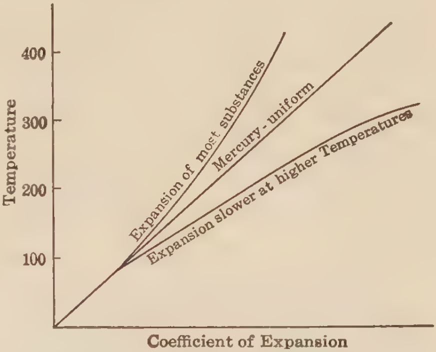


FIG. 27. — Mercury expands uniformly.

24. Fahrenheit's contribution. Fahrenheit, though a German by birth, established himself as a maker of philosophical instruments in Amsterdam while yet a young man. About 1706 he began making thermometers whose excellence made him famous throughout many foreign countries. He used alcohol at first, and later mercury, in his thermometers. He not only did much to improve the accuracy of measuring temperatures, but also devised the scale which is in use on our common thermometers today. The lowest temperature that he obtained with a mixture of ice, salt and ammonium chloride, he called *zero*. The proportions of these substances in the mixture are not known. When these salts are used

singly with snow, it has been determined that three parts snow to one part salt gives a temperature below zero, and four parts snow to one part ammonium chloride gives a temperature just above zero. The next fixed point on Fahrenheit's scale was the temperature obtained by mixing water and ice. This point he marked thirty-two. In preparing a Fahrenheit scale today we use the freezing point of water (32°) and the temperature of steam from water boiling at standard atmospheric pressure (212°), for the two fixed points, from which the entire scale may be marked off into degrees.

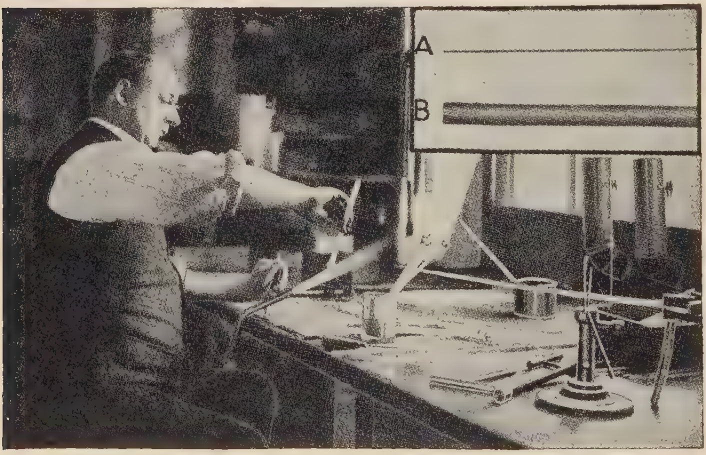


Fig. 28. — Filling a thermometer with mercury. Insert compares bore of thermometer tube (*A*) with human hair (*B*).

25. Making a mercury thermometer. Thermometer making requires great skill; if a thermometer is to be accurate, the materials must be tested and selected with exceptional care, by experts. The thermometer tubing has a fine bore, sometimes finer than the diameter of a human hair. A bulb is blown in one end of the tube. It is heated to expand the air and quickly inverted in mercury. As the bulb cools,

mercury partly fills it. This mercury is boiled and the tube again inverted. This is continued until no air is left in the bulb. When the proper amount of mercury is in the thermometer, the stem is sealed by means of a blowpipe gas flame. The fixed points for a scale are determined by placing the bulb in water of known temperatures, say 32° F., 62° F. and 92° F. These points are scratched on the glass tube, and intermediate temperatures are marked upon a scale, to which the tube is attached.

26. Oven thermometers. Two types of thermometers are used on oven doors to indicate the temperature within the oven. One of these is the mercury thermometer; the other makes use of the expansion of a metal, or more commonly, of two metals joined in one bar. In the dial thermometer of this type, Fig. 29, a curved bar is made by fastening at short intervals a strip of brass to a strip of iron. The greater expansion of the brass, which is on the inside, makes the bar straighten a little. As it does so, the cord "C," which makes a loop around the drum attached to the pointer, causes the pointer to move along the scale and indicate the temperature.

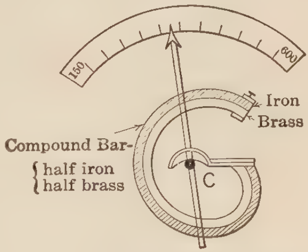


FIG. 29. — Dial thermometer on oven door.

27. Household thermometers. We are gradually outgrowing guesswork in regard to temperatures, but even now there is ample opportunity to replace temperature guesses by temperature facts in the household. In an efficient household of today the thermometer is a commonly used instrument. Most of our household thermometers are mercury thermometers, which differ from one another chiefly in the scales used. See illustrations on pages 4 and 5.

The clinical thermometer, Fig. 6, differs from the others in being self-registering. A constriction in the bore of the

stem, just above the bulb, makes this registering possible. When the mercury expands, it is pushed through this narrow place into the stem, but when it cools and contracts the thread of mercury is broken by this constriction, and the mercury column is left in the tube registering the highest temperature which was reached. A quick-acting clinical thermometer has a very small bulb and will give maximum temperature in half a minute. A slow-acting clinical thermometer has a large bulb and requires three minutes.

Table IV

SIGNIFICANCE OF THE READING OF A CLINICAL OR FEVER THERMOMETER

Below 98.6°, subnormal temperature,
98.6°, normal temperature,
99°–101°, slight fever,
101°–103°, moderate fever,
103°–105°, high fever,
105°–106°, very high fever — extremely dangerous.
When the temperature is over 101° it is best to call a physician.

Thermometers are delicate instruments, and must be used with care. The glass bulb is thin, to permit the quick conduction of heat. The expansive force of mercury is very great; so great in fact that if the bulb is heated after the mercury column reaches the top of the bore, it will break the glass at its weakest point, which is the bulb.

28. Maximum and minimum thermometers. Sometimes it is important to have records of how low or how high the temperature goes during a certain period of time, without watching the thermometer. A type of self-recording thermometer, Fig 30, known as the "Sixe's," after the man who designed it, is capable of giving the maximum and minimum temperatures. This thermometer is a U-shaped tube, usually having a cylinder at one end and a bulb at the other. The lower half of the U tube holds a column of mercury. Creosote fills the cylinder and half of the bulb; the remaining space in the bulb is filled with air. In the tube, at either

end of the mercury, are two markers, which are pushed one way or the other by the moving mercury. These markers are glass tubes, in which fine strips of steel have been sealed so that they can be moved with a magnet when it is desired to set them. They can be pushed by the mercury, but a hair-like projection holds them tightly, so that they will not move from their own weight. When the creosote in the cylinder expands, the mercury is pushed up the right-hand side of the tube, and the marker is carried with the mercury. When the creosote cools and contracts, the compressed air in the bulb pushes the mercury column down the right-hand side of the tube, leaving the marker to register the maximum temperature. At the same time, the mercury is pushed up the left-hand side, carrying the other marker at its surface. In a similar way this marker will register the lowest temperature.

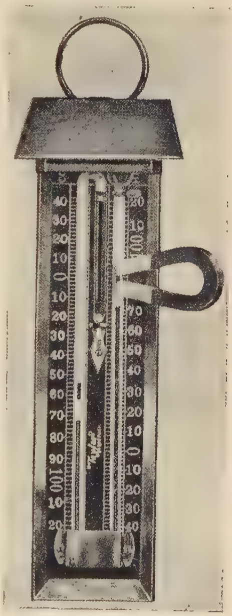


FIG. 30. — A Sixe's maximum and minimum thermometer.

Another type of high-and-low thermometer makes use of two thermometers set horizontally. The one to register maximum temperature holds mercury, but is so constructed that the mercury will not draw back into the bulb upon cooling. The minimum thermometer holds alcohol. In the stem is an index surrounded by alcohol. This index is drawn back by the surface film of the alcohol when the alcohol cools; but when the alcohol expands, it moves away from the index which marks the lowest temperature.

29. High-pressure thermometers. Most thermometer tubes are sealed when the mercury nearly fills the tube.

When the mercury contracts, a partial vacuum is left in the bore of the tube above the mercury. When thermometers are used to measure temperatures higher than the normal boiling point of mercury, the space above the mercury is filled with a gas, usually nitrogen or argon. As the mercury expands it compresses the gas, which in turn presses equally upon the mercury. Pressure prevents the mercury from boiling and so makes it possible to use mercury to measure temperatures higher than the normal boiling temperature of mercury. These thermometers must be made of strong glass to withstand this high pressure.

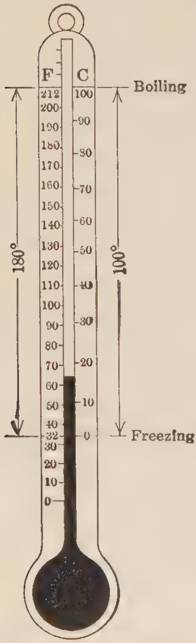


FIG. 31.—Comparison of Fahrenheit and Centigrade scales.

30. The Centigrade thermometer. In 1742, Celsius, a Swedish scientist, proposed a thermometer scale in which 0° should mark the boiling point of water and 100° the freezing point of water. These readings were later reversed by a French scientist, and the resulting thermometer is the **Centigrade thermometer,** which is in use in practically every part of the civilized world, except England and the United States. Even in these two countries the Centigrade thermometer is used in scientific work, and in other countries it is in use for both common and scientific temperature measurements. On the Centigrade scale, water freezes at 0° and boils at 100°. This is a more scientific scale than the awkward one devised by Fahrenheit.

31. Comparison of Fahrenheit and Centigrade readings. The freezing point of water is 0° Centigrade and 32° Fahrenheit, Fig. 31. The boiling point of water is 100° Centigrade and 212° Fahrenheit. It is therefore seen that 1 Centigrade

degree = 1.8 Fahrenheit degrees. By using these equivalents and remembering always that the freezing point of water is the common reckoning point for the two scales, it is an easy matter to calculate one scale reading from the other. For example, when the house thermometer reads 68° Fahrenheit, what would a Centigrade thermometer read in the same place? From 68° to the freezing point there are $68° - 32° = 36$ Fahrenheit degrees. 1° Centigrade = 1.8° Fahrenheit, hence $36 \div 1.8 = 20°$ Centigrade. The Fahrenheit reading of 68° is equivalent to a Centigrade reading of 20°.

32. Absolute zero. We already know that the heat in a body is due to the vibration of the molecules, and that as the molecules vibrate more slowly the body becomes cooler. It is believed that molecules possess heat as long as they vibrate, and that they can give out heat as long as they can "cool" or reduce their vibration rate. If a molecule ceases to vibrate, it has no heat. It is then at its lowest possible temperature, which is called **absolute zero.** Absolute zero is −273° C. and −459° F., and is believed to be the temperature of space which surrounds the earth and all the heavenly bodies.

33. Range of temperature. In the household the range of temperature is comparatively small, and thermometers with suitable scales are approximately as follows:

Weather	thermometer	−40° F. to 120° F.
Bath	"	50° F. to 120° F.
Milk	"	40° F. to 212° F.
Clinical	"	90° F. to 110° F.
Candy	"	120° F. to 390° F.
Oven	"	150° F. to 600° F.

In nature, however, we have a greater range of temperature, extending from about −90° F. in polar regions to above 120° F. in the desert, and to 3000° F. in the molten rock issuing from volcanic fissures. When Fahrenheit first

made his thermometer, he made the zero of his scale the lowest temperature he had produced artificially with a mixture of salt, ammonium chloride and ice. He thought that it was the lowest possible temperature. Not only has natural cold been found lower than this, but vastly lower tempera-

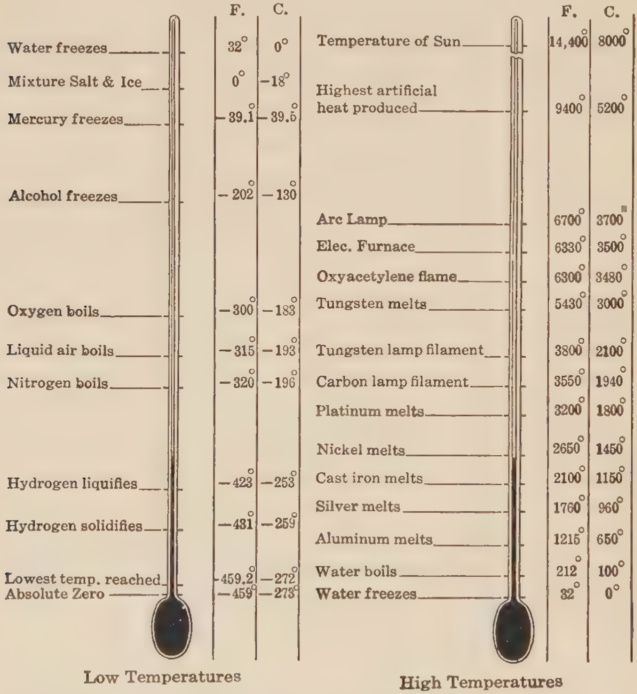


FIG. 32. — Range of temperatures from absolute zero to the temperature of the sun.

tures have been produced artificially since his time. Scientists have produced a temperautre within 2 degrees of absolute zero. Some of our highest temperatures are produced in the electric furnace; but all temperatures used in our industries, and even the molten lavas of the earth, are cold compared with the temperature of the sun, which is esti-

mated to be about 15,000° F., while some of the stars possibly have a temperature of 30,000° F. Temperatures much higher than those of the sun and the stars have been produced momentarily by passing an enormous amount of electrical energy through a very fine wire. A temperature of 50,000° F. is believed to have been produced in this way.

PROBLEMS

1. Alcohol freezes at −112° Centigrade. What is its freezing point Fahrenheit?

2. Alcohol boils at 77.9° Centigrade. What is its boiling temperature Fahrenheit?

3. When the refrigerator temperature is 50° F., what would be its temperature Centigrade?

4. The normal body temperature is 98.6° Fahrenheit. What is it Centigrade?

5. What Centigrade reading corresponds to 0° Fahrenheit?

SUMMARY

1. Galileo made the first thermometer. Fahrenheit devised the awkward scale of our common thermometer. The Centigrade scale is the one used in scientific work.

2. The measurement of heat depends upon the relation between expansion and change in temperature, which are two of the important effects of heat.

3. Expansion of solids, of liquids, or of gases may be used in measuring temperature.

4. Mercury is best adapted for measuring ordinary changes in temperature. Alcohol is best for low weather temperatures.

5. Self-registering thermometers make use of several different means of registering the temperature, in the clinical and maximum and minimum thermometers.

6. Mercury thermometers for measuring temperatures higher than the boiling point of mercury are made by enclosing gas under pressure in the stem above the mercury column.

7. Fahrenheit scale reading − 32 = Centigrade scale reading × 1.8.

8. Absolute zero is the lowest conceivable temperature. It is the temperature at which the molecules of matter cease to have any vibration.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. Special thermometers for special purposes.
2. Liquid air and low temperatures.
3. Make an alcohol thermometer.
4. Test readings of various home thermometers by comparison with a standard.

REFERENCE BOOKS

Bolton. *Evolution of the Thermometer.* Chemical Publishing Company.

Jameson. *The Thermometer and Its Family Tree.* Taylor Instrument Company.

CHAPTER IV

VENTILATION

34. Simple means of ventilation. When a fireplace is used, there is good ventilation because much air, in excess of that required for burning the fuel, escapes up the chimney. Fresh air enters through cracks about the doors and windows, and may even come, to some extent, through the walls. A stove gives very little ventilation, because there is not much air carried up the chimney. The air supply, in warm-air furnace heating, gives ample ventilation, if the supply is drawn from out-of-doors.

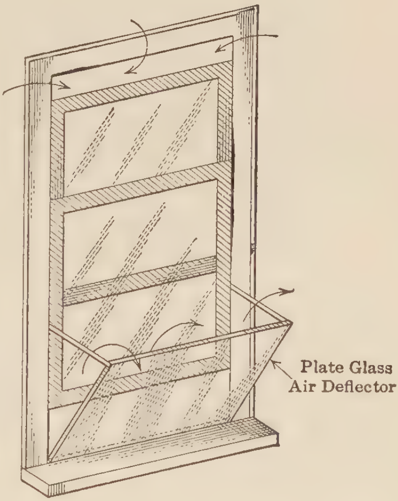
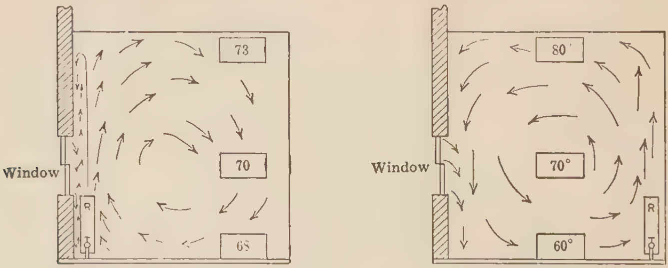


FIG. 33. — Ventilation without a draft.

Since the warmer air is in the upper part of the room, opening the window both at the top and bottom will effect a natural circulation. It is well to have some deflecting surface to meet the entering air, and prevent a direct draft into the room, as in Fig. 33. If the air is deflected upward, it will diffuse more readily, and a person in front of the window will be protected. Plate glass makes a good deflecting surface and has the added advantage of permitting light to enter undiminished. Kitchen odors may be removed by

Fig. 34. — Window fan and panel and its use in the kitchen.



Radiator properly placed.
A fairly uniform temperature
results at different levels.

Radiator improperly placed.
Wide differences in temperature
result at different levels.

Fig. 35. — Importance of the position of the radiator.

having a fan set in a panel above the window as shown in Fig. 34. It is better to place a radiator under a window than against an inside wall, as this insures more even distribution of heat in the room, as is shown in Fig. 35.

35. Ventilation by flue radiators. A flue may pass from beneath a radiator through an outside wall, as in Fig. 36, in order to secure a supply of fresh air. Dampers in this flue regulate the amount of air which enters. To heat this additional air will probably require an increase in fuel consumption of about 25 per cent, but the ventilation secured is worth the extra expense, especially if many people are accustomed to use the rooms.

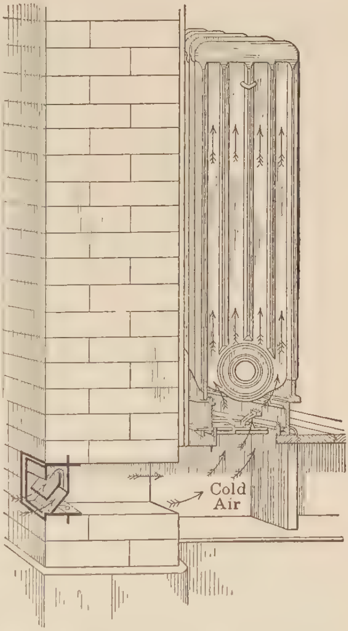


Fig. 36. — A good way to bring fresh air into the house.

36. Ventilation by indirect heating. In order to heat a room and to secure the same renewal of air that the flue radiator gives, without having the radiator in the room, the indirect heating method, shown in Fig. 37, is used. In this system a steam radiator is placed in a box-like chamber near the top of the cellar, and at least 2 feet above the water line in the boiler. Cold out-of-door air is brought through a duct to this chamber, is heated, and carried to the rooms by convection. A damper placed in the duct supplying the cold air should be so arranged that it will automatically shut off the air when the heat is shut off from the radiator.

This system, unless combined with direct radiation, gives more ventilation than is needed and therefore, if used alone, wastes fuel.

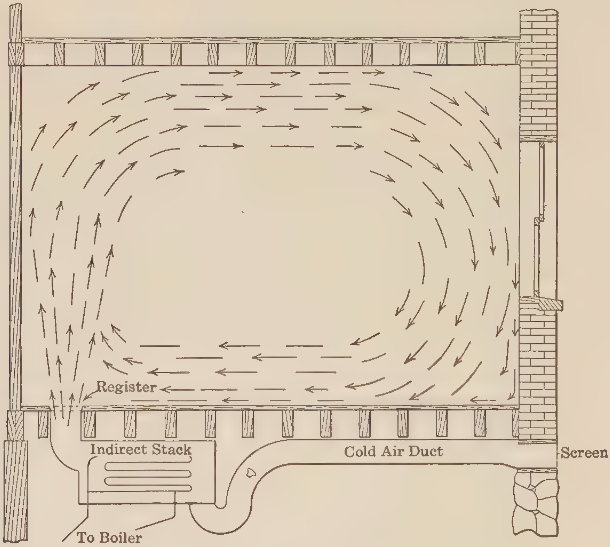


FIG. 37. — Indirect heating brings fresh air into the rooms.

37. Regulation of humidity. In those seasons of the year when we use no artificial heat, we cannot easily change the humidity of the air. On excessively hot and humid days in summer we should like to remove the moisture, but there is no inexpensive way to do this. In winter the cold air has very little moisture in it. When this air is heated, the relative humidity frequently drops to 20 per cent, sometimes to less than 10 per cent. At times the air in our houses is drier than the air on the desert. Such dry air parches the skin, and dries the throat, making it uncomfortable and subject to the attacks of bacteria. Not only does excessively dry air make one irritable, but it is debilitating as well.

In most of our hot-air furnaces there is a water tank to supply water to the air which is warmed and sent to the rooms. This tank, under ordinary conditions, does not supply one-tenth of the moisture needed to make the air comfortable and healthful. The air ought to have a relative humidity of about 60 per cent; but it is impracticable to have over 35 per cent to 40 per cent in cold weather, because of the excessive condensations on cold surfaces such as walls and windows. Damp walls and frosted window panes often result when the moisture in the air is just right from a health standpoint. In order to maintain a humidity of 40 per cent in the average-sized, well ventilated house heated by warm-air furnaces in very cold weather, 8 or 10 gallons of water must be evaporated each twenty-four hours. With the proper humidity, the room is comfortably warm at a temperature several degrees cooler than when the air is dry. Proper humidity is thus a factor in saving fuel. Figure 38 shows a spray humidifier for regulating the humidity of the air supply.

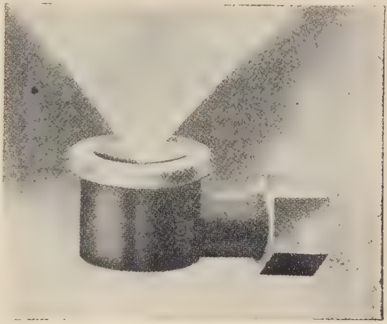


FIG. 38. — A water spray is sometimes used in the hot air chamber to increase the humidity.

38. Mechanical ventilation. So far we have considered methods of ventilation in which the movement of air was effected naturally, by gravitation. This is the case in the majority of our homes. The gravitation system works best in cold weather; in warm weather there is very little circulation of air through the house. In large buildings, schools, halls, and factories, natural or gravity circulation of air is not satisfactory, and some method of mechanical

ventilation must be employed. Often an indirect heating system is used in which air is forced to circulate by means of a "blower" or enclosed fan, as in Fig. 39. This system of securing ventilation is frequently combined with either the hot-water or steam heating system, in which radiators are placed in the rooms. When this combination is used, only enough air is circulated to secure satisfactory ventila-

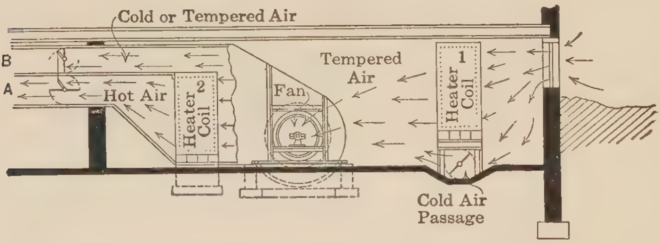


FIG. 39. — In a mechanical ventilating system it is possible to change the condition of the air at will.

tion. This system has an advantage for schools and factories, in that the fan circulation of air may be stopped when the occupants have left the building. The separate heating system makes it possible to keep the building warm without the circulation of air.

39. Systems of mechanical ventilation. When air is forced into the rooms by fans located in the basement, the pressure indoors is slightly greater than the atmospheric pressure. This **pressure system,** sometimes called the **plenum system,** gives a positive circulation of air under all weather conditions. Because of the great pressure, there is some escape of air from the rooms through cracks around doors and windows, but no air enters through these places.

When air is drawn from a building by fans placed at or near the top of the ventilating flue, the pressure in the rooms is slightly less than atmospheric pressure. This is the **exhaust** or **vacuum system.** Air passes into the room through

the air ducts, but it also comes in through cracks and crevices. For this reason, as a rule, outside weather conditions interfere with an exhaust system more seriously than they do with a pressure system.

40. Inlets and outlets. Proper distribution of fresh air in the room can only be secured by a proper arrangement of inlets and outlets. It takes time for new air which has been brought into a room to diffuse and dilute other air in the room. If the hot air enters near the floor and leaves near the ceiling, it will pass through the room so rapidly that little diffusion will take place, while the escaping air will consist, for the most part, of the pure air which has just entered.

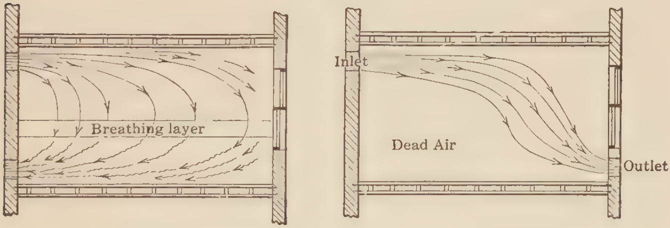


FIG. 40. — Good and bad ventilation practice in schools.

When the inlet is near the ceiling and the outlet is near the floor on the opposite side of the room, Fig. 40, a large portion of the air in the room remains stagnant. When the inlet is near the ceiling and the outlet at or near the floor on the same side of the room and diagonally opposite to the inlet, a gradual settling, diffusion and mixing results, so that practically all parts of the room are benefited by it. The inlet and outlet should be in the inner wall rather than in an outside wall.

41. Air mixing system. When the heating is done entirely by the circulation of hot air, it is necessary at times to admit air at a lower temperature. This is made possible by having

two heating stacks and two air ducts, as shown in Fig. 39. Cold air passes over heating stack No. 1, and becomes "tempered air." The fan draws air from the tempered-air room and forces a part of it over heating stack No. 2, which produces hot air in duct *A*. The other portion of the tempered air passes from the fan to duct *B*. The hot and cool (tempered) air may be mixed in any proportion, or either supply may be entirely shut off from the room by means of the mixing damper.

42. Recirculated air. The discharge of all the hot air from a room into the outer air and the heating of other fresh air to provide ventilation requires a large consumption of fuel. Experiments indicate that a saving may safely be made by recirculating the air. If the air is filtered and washed, its impurities are removed in a large measure, but as it is not cooled to a very low temperature, the reheating requires but little fuel. In tests made in schools, pupils have been found to do practically as good work in recirculated air as in fresh air. Odors are more noticeable in recirculated air than in fresh air; the amount of carbon dioxide may be increased to ten times that in normal air, without harm.

43. Objections to recirculated air. Recirculated air, under ordinary conditions, contains more bacteria than fresh air brought in from out-of-doors. Unless the washing process is carried out with great care, there is danger in using recirculated air in public buildings. Out-of-door air, under the action of the ultraviolet rays, acquires a property difficult to describe, but which we may call *active*. This active property is lost when the air is breathed. Window glass excludes most of the ultraviolet rays, so that sunlight in the house cannot revivify the air which has once been polluted by breathing.

44. Cloth window ventilation. The substitution of thin, stout cloth for the glass of windows has been tried with good success in sleeping rooms and hospitals. The cloth frees

the air from dust, and gives a slow movement to the air, preventing drafts. This system of ventilation also helps to secure out-of-door humidity.

SUMMARY

1. Ventilation is the means of bringing a supply of fresh air to the occupants of our rooms. Ventilation is accomplished by natural circulation, by drafts caused by fires in fireplaces and stoves, and by forced ventilation by the use of fans.

2. Flue radiators give ventilation by drawing fresh air through a duct passing beneath the radiator, through the outside wall. Indirect heating secures ventilation on the same principle, but with the radiator placed in the cellar, over which air from out-of-doors passes before going to the rooms.

3. Humidity of the air is an important factor in determining the amount of coal burned in winter, and in preserving our health.

4. In large buildings, mechanical ventilation is essential. In the *plenum system*, the air is pushed into the rooms by a blower. In the *exhaust system*, air is drawn from the room by means of a fan.

5. The best arrangement of inlet and outlet in a mechanical system is to admit air near the top of the room and to have it escape near the floor on the same side as the inlet and diagonally opposite.

6. Sometimes air from the rooms is returned to the heater and recirculated. This will save fuel in cold weather, but if many people use the rooms it is not satisfactory. If the recirculated air is washed and filtered, it may be used without harm, but often it lacks a certain " active " principle which is present in fresh out-of-door air.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. Natural vs. mechanical ventilation.
2. Advantages and disadvantages of recirculated air.
3. Compare the time of drying a wet cloth in still air and in moving air. (Use an electric fan.)
4. Test ventilating openings — window cracks, high and low; doors, top and bottom — to determine the direction of air movements in a room.

REFERENCE BOOKS

Allen. *Notes on Heating and Ventilation.* Domestic Engineering Company.

Packard. *Everyday Physics* (page 37). Ginn and Company.

Heating and Ventilation. Catalogue No. 213. Sturtevant Engineering Series. B. F. Sturtevant Company.

CHAPTER V

HOW HEAT TRAVELS

45. Movement of heat. A pudding just out of the oven is set into a pan of cold water to cool it quickly. If a thermometer is placed in the pudding and another in the water, it will be observed that as the pudding grows colder the water becomes warmer. A cold flatiron is placed on the hot stove, and in a short time the flatiron is hot. A hot-water bottle warms the bed clothing near it. When removing a skillet of boiling water from the gas flame, you find that the metal handle, which was not near the flame, is too hot for you to hold in the bare hand. The water in the skillet has been warmed to the boiling point, though separated from the flame by the metal. From this evidence you reason that the heat derived from the gas has traveled through the metal and entered the water; also that the heat has traveled from the heated part of the metal to the cold part; and that when you touch the handle, which is hotter than the hand, heat travels into your hand.

These examples illustrate an important property of heat, namely, that *when any two bodies of different temperatures are in contact, heat passes from the body of high temperature to the one of low temperature*, and that in a single substance heat moves from points of high temperature to points of low temperature. This kind of heat travel is called **conduction.**

Conduction explained. The scientist explains the conduction of heat as follows: All bodies of matter are made up of very small particles or molecules, which are always in vibration. The addition of heat to a body makes the molecules vibrate more rapidly. It is therefore believed that the molecules in a hot body are vibrating more rapidly than they are in the same body when its temperature is lower. The

adjacent molecules, while not in permanent contact with each other, do come together and strike frequent blows upon each other. Molecules having greater energy will give up some of this energy to those with less, and these in turn carry it on to still other molecules, so that in time molecules far removed from the source of heat will receive some of the transmitted energy by this process of conduction.

Since heat flows from places of high temperature to those of low temperature, objects which have been in contact with the air of the room for a time will all have the same temperature. They do not all "feel" the same tempera-

FIG. 41. — These objects may have the same temperature and yet some of them feel colder than others. Why?

ture, as was explained in Chapter I. Suppose the air is at a temperature of 70 degrees, and we touch a brass candlestick, a glass dish, and a woolen sweater. If we judge by the sense of feeling alone, we say that the brass is cooler than the glass or wool, and the wool is warmer than the brass or the glass. Since in reality they are all at 70 degrees, how is it that we are deceived? A simple test will make it possible to answer this question.

Hold an 8-inch brass rod in one hand and an 8-inch glass rod in the other. Let the free ends of these rods extend

into a gas flame. Which one brings the heat to the hand first? Is this substance a better conductor of heat? If a wooden rod is used, will it bring heat as well as the metal? If the metal rod brings heat to you faster than the glass or the wood does, what would you expect when you touch rods of iron, or glass, and of wood, which are all at the same temperature and all colder than the hand? Which one will take heat from the hand most rapidly?

It must be evident to you now that if you place your hand upon different objects having the same temperature and colder than the hand, heat will be conducted away from the hand by all of them; but since metals are better conductors of heat than glass they will remove more heat, and since they remove more heat the hand will feel cooler. Likewise, since glass conducts heat better than wool, it will feel colder than the wool.

46. Advantages of good conductors and of poor conductors. Have you ever used an aluminum saucepan with an aluminum handle, with an iron handle, and with a wood-covered handle? If you have, you can appreciate the disadvantage of the aluminum handle, the improvement made by the use of the iron handle, and the still greater advantage of wood. Aluminum conducts heat four times as well as iron and one thousand times as well as wood. An aluminum kettle transmits the heat to the contents around the sides almost as well as on the bottom, but an iron kettle transmits comparatively little heat around the sides. Aluminum has the advantage of giving the heat quicker, and of distributing it more evenly to the material within it. It is, therefore, an ideal material for many types of cookers.

47. Heat insulators. Some substances are such poor conductors of heat that they may be called *heat insulators.* There are two uses made of this property: to keep heat away, and to hold the heat in. We pack ground cork and use layers of felt in the walls of a refrigerator to keep heat out, and mineral wool or magnesia in a fireless cooker to

Table V

RELATIVE THERMAL CONDUCTIVITIES

Silver	1.0	Asbestos paper	.00045
Copper	.9	Linoleum	.00036
Aluminum	.5	Dry soil	.00034
Brass	.27	Cork carpet	.00026
Iron	.14	Asbestos felt	.00025
Platinum	.06	Flannel	.00023
Rock	.0025–.009	Silk	.00022
Cotton cloth	.0053	Mineral wool	.0002
Brick	.002–.005	Sawdust	.00018
Ice	.005	Wood (soft)	.00015
Porcelain	.0025	Paper	.00013
Cement	.0022	Cork board	.00012
Granite ware	.0017	Wool	.00010
Glass (ordinary)	.0016	Hair felt	.00010
Water	.0014	Cotton wool	.00009
Plaster	.001–.0015	Feathers	.000057
Dry white sand	.0009	Dry air	.00005
Wood (hard)	.0006		

Table VI

THERMAL CONDUCTIVITY

(In calories per sec. per sq. cm. per degree C. per cm. thickness)

Vacuum-silvered jacket 0.001 mm. pressure	.000002
Air (no convection)	.000060
Calorox (fluffy mineral matter)	.000076
Kapok (loose vegetable fiber)	.000082
Pure wool (6.9 lbs. per cu. ft.)	.000084
Pure wool (5 lbs. per cu. ft.)	.000090
Pure wool (25 lbs. per cu. ft.)	.000101
Hair felt	.000085
Mineral wool (loosely packed)	.000090
Cotton wool (loosely packed)	.000100
Cork board (low density)	.000096
Cork board (high density)	.000106
Celite (infusorial earth)	.000106
Wool felt	.000125
Wall board	.000150
Asbestos paper	.000170
Insulex (asbestos and plaster)	.000194
Fire felt (asbestos and cement)	.00021
Cypress (across grain)	.00023
Asphalt roofing (felt and asphalt)	.00024
White pine (across grain)	.00027
Oak (across grain)	.00035
Hard maple (across grain)	.00038
Gypsum plaster	.00078
Asbestos wood (asbestos-cement)	.00093

keep the heat in. We lay pads on the table under hot dishes to keep the heat from reaching the table, and we put a wool jacket around the coffee pot to prevent its losing heat. But whether it is to save the heat or to protect something from the effect of heat, the poor conductor is an efficient and effective agent. As a rule, we desire to prevent loss of heat

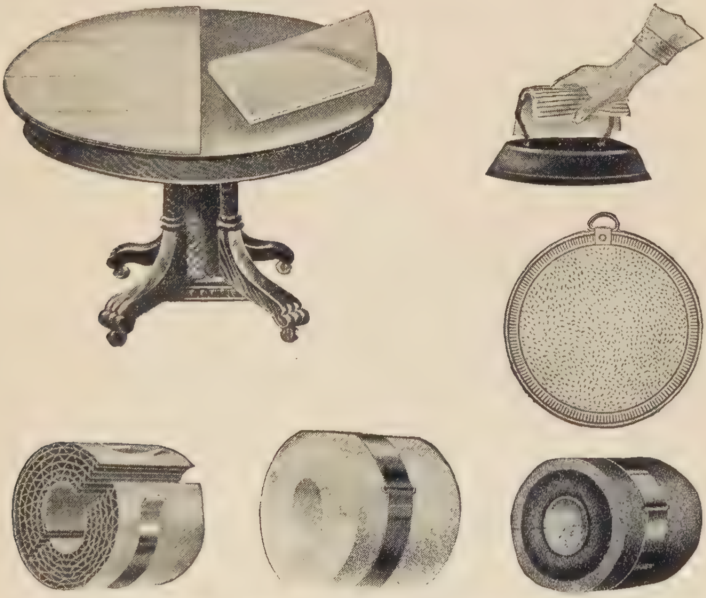


FIG. 42. — Household uses of asbestos. Table cover, flatiron holder, stove mat and three pipe coverings in the order of pictures, air cell, 85% magnesia, and hair and woolfelt.

from steam pipes. This is done by surrounding the pipes with a heat insulator, such as magnesia or asbestos.

It has been estimated that in home heating systems 25 per cent of the fuel used is now lost. This is an average waste of two tons of coal a year per family. If pipes and furnaces were covered with asbestos, this loss could be reduced to one-half ton.

In the storage of ice, the ice is surrounded by dry sawdust. The thicker the layer of sawdust the less heat will penetrate

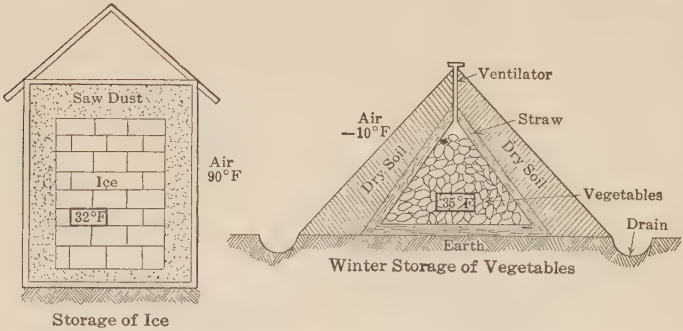


FIG. 43. — Preserving ice and vegetables by means of heat insulators.

FIG. 44. — Firefighter, clothed in asbestos.

it to melt the ice. Storage of vegetables through the winter is possible by utilizing the protection of dry soil. A central pit holds the vegetables. These are covered first with a layer of straw and then with a thick layer of earth as indicated in Fig. 43. There must be good drainage to keep the vegetables and soil dry.

Dry air is a poor conductor of heat. The value of double windows and storm doors is due to the poor conduction of heat by the enclosed air. The warmth of fur, wool and other clothing is largely due to air held in the spaces between the fibers. Air spaces between the roof of a house and the ceiling, and

air spaces within the walls, prevent the penetration of the extreme heat on a hot summer day. Heat insulators are of great importance in ice storage.

QUESTIONS

1. Why does sawdust give better protection against heat than the solid wood from which the sawdust comes?

2. Asbestos is a better conductor of heat than air. Why then, in order to save heat, do we wrap steam pipes in asbestos rather than allow them to be surrounded by the air of the room?

48. Convection currents. In Chapter II we saw how heat produces a difference in density in liquids and gases, and how under the force of gravity this results in the actual flow or motion of some of the heated material from one place to another, thus transporting heat from the heat source to places remote from it. These currents, called *convection currents*, are very important in everyday life. In the home we depend upon them very largely in warming the house, in automatically supplying fresh air to the fire, and in promoting ventilation.

49. Heat from the sun. Day after day, the sun sends out a steady stream of heat, without which there could be no life on the earth. Did you ever stop to think, "How does this heat get here?" We have learned of two ways by which heat can travel, namely, *conduction* and *convection.* These modes of travel require the assistance of matter, and there is no matter connecting the earth and the sun. The air of the earth extends, at the most, only a few hundred miles, while the heat energy from the sun must traverse a space of 93,000,000 miles to reach us. Evidently there must be some way for heat to travel entirely independent of matter. Most scientists believe that all space is filled with an invisible, weightless medium quite unlike matter, called **ether,** which is able to transmit heat energy for any distance without loss.

50. Radiation. Energy, radiated from the sun, travels as ether waves. Light, as well as heat, travels in the ether. Electrical energy borne by the ether carries the radio broadcasts and wireless messages. Ether waves vary in length and frequency of vibration. The longest waves are the electrical waves used in radio. Heat waves are shorter than the radio waves, but longer than those which produce light. All these waves are forms of radiant energy. The transmission of energy by means of ether waves is called *radiation.* Since ether is present everywhere, even between particles of matter, energy may be radiated through matter. The heat we feel when we stand before a fire in a fireplace does not reach us by conduction, because air is the poorest of all conductors; neither does it come by convection. It does come to us by radiation. The molecules of matter interfere to a slight degree with the passage of radiant energy, and yet the speed of ether waves through some forms of matter is nearly as great as it is in space containing no matter.

Relation of ether waves to molecular motion. When heat and light ether waves are absorbed by matter, they increase the molecular vibration and so raise the temperature. Molecular vibration in an object will set up ether waves, and when this happens, energy is lost by the body. Every object, then, may be considered as radiating heat and also as receiving radiant heat from other bodies. At high temperatures, ether waves of shorter length are produced, and light results.

51. Radiation and absorption. Why is the bottom of the tea-kettle dull and rough, and the inside surface dull and rough, while the exposed outside surface is bright and smooth? Let us pour equal quantities of hot water into two metal cans, one of which has a dull, black, rough surface, and the other a bright, white, smooth surface, Fig. 45. The temperature of the water in the two cans at the start is the same. If we observe the thermometer in each can at ten-minute intervals, it will be seen that the water in the black, rough can is cooling faster than that in the bright,

smooth one. A time-temperature curve for each of the cans is shown in Fig. 45. This is due to the fact that one is radiating heat faster than the other. A smooth, bright surface helps to retain the heat.

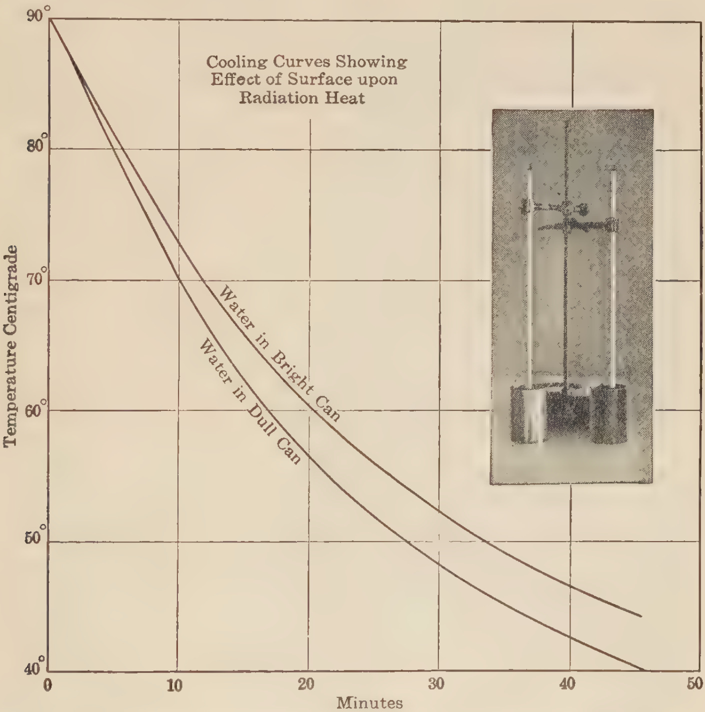


FIG. 45. — Curve shows that the dull black can radiates heat faster than the smooth white can does.

If the bulb of an air thermometer is carefully coated with soot from a candle, we may change its surface to a dull black. Support this thermometer and another similar one whose bulb is bright and smooth about 8 or 10 inches apart. If a flame is placed half-way between them, as in Fig. 46, and the thermometers noted at intervals, we find that the greater rise in temperature occurs in the thermometer whose

bulb was coated with lamp-black. It is evident, then, that the dull, black, rough surface absorbs radiant heat better than the smooth, polished surface. In a similar way, when the sun shines upon a black cloth and a white cloth, both covering snow, it is found that more snow melts under the black cloth than under the white one. The black absorbs, while the white reflects, the greater part of the radiant energy. Radiators are best when dull and rough, and the hot-air ducts lose less heat when bright and smooth. Radiators covered with non-metallic paint radiate 15% to 20% more heat than those covered with aluminum or bronze paints.

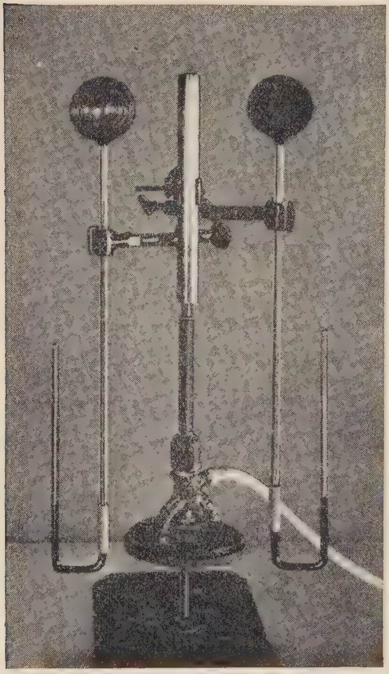


Fig. 46. — Apparatus arranged to show absorption of heat. The flame heats a brass cylinder placed equidistant from two air thermometers, one with a smooth glass bulb (at left) and the other with its bulb coated with lamp-black (at right).

52. The vacuum bottle. When objects are heated or cooled, all three methods of heat movement are usually involved. A hot iron *conducts* heat to the air in contact with it. This heated air is removed, and other cold air brought into contact with the iron, by *convection*. The iron also *radiates* heat in all directions.

It is desirable at times to prevent the loss of heat from foods and drinks, or the access of heat to them. The vacuum

bottle, Fig. 47, and the vacuum fruit jar are very efficient devices for accomplishing this. A double glass bottle, really one bottle within another, connected only at the mouth, holds the liquid to be kept hot or cold. Air is removed from the space between these two bottles, to prevent conduction across the space. The walls of the vacuum space are silvered, and are thus made to reflect radiant energy like a mirror. Heat radiated from the inner bottle across the vacuum is largely reflected back by the silver mirror on the outside of the vacuum. The glass itself is a poor conductor and is separated from the outside metal container by an air space. It is thus made so difficult for heat to travel in either direction across the space that hot liquids keep hot and cold liquids keep cold for many hours. A wide-mouth container, for

FIG. 47. — Take down view of a vacuum bottle. The parts shown are metal cap or drinking cup, metal shoulder with leak-proof gasket, metal case, cork stopper and double-walled glass filler standing in a shock absorber.

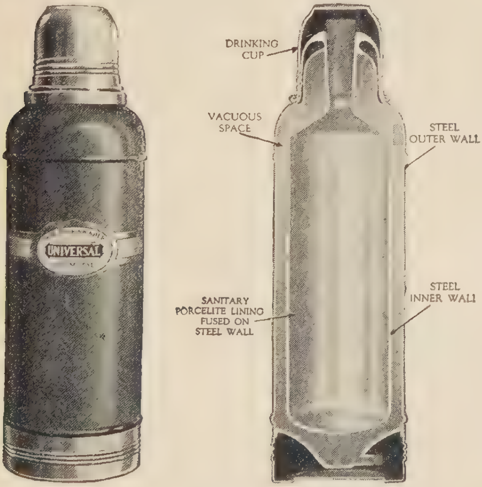


FIG. 48. — Non-breakable enameled steel vacuum bottle.

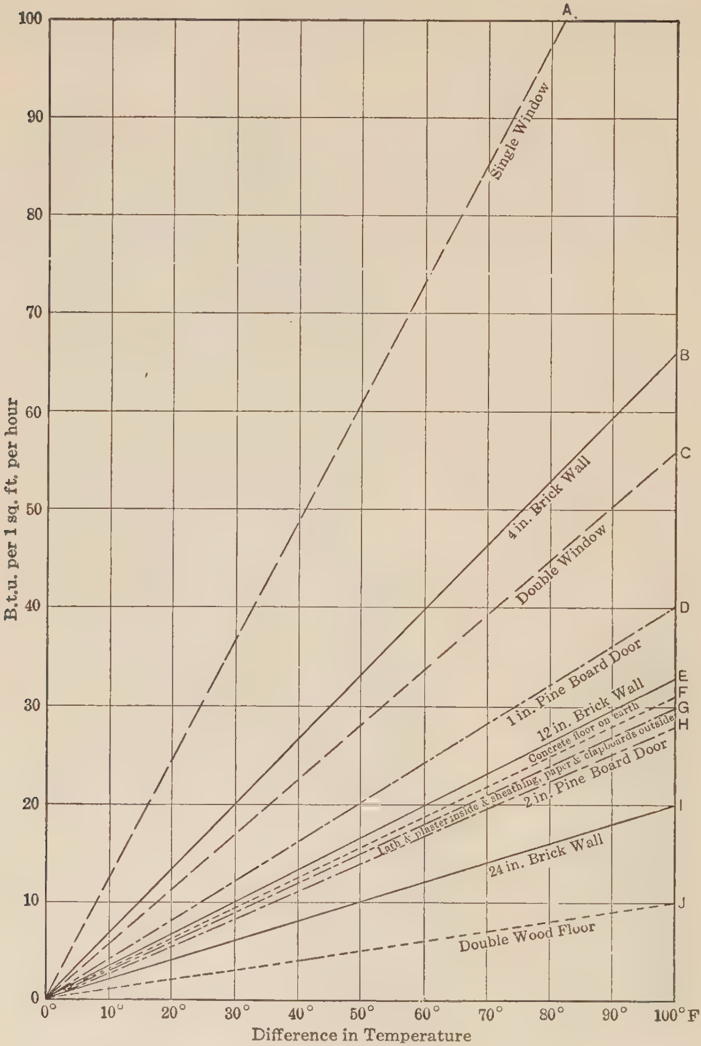


FIG. 49. — Heat losses through building materials under moderate exposure to wind.

holding foods other than liquids, is made on the same plan. In place of glass, a double-walled enameled steel bottle may be used. This is very efficient and is in less danger of breaking.

53. House construction. Most of the time, it is desirable to have the walls of the house check the passage of heat through them, in cool weather to keep the heat in, and in hot weather to keep the heat out. The heat-insulating property of air, paper, wood, and other materials is utilized in buildings. The wall of the ordinary wooden house has, in its cross section, clapboards, sheathing paper, boards, air, lathes, plaster, and wallpaper. These are all poor conductors. Many cement and stucco houses have hollow tile walls to hold the surface cement. Air is held in small spaces in the tile, and large convection currents, such as take place in the walls of wooden buildings, cannot be produced. Rooms directly under flat roofs are very hot under the direct rays of the summer sun. The pitched roof, having an attic space which holds air, is much cooler. Thick walls with small air spaces keep the heat in or out better than thin walls or solid walls. The loss of heat through the walls depends upon the outside and inside temperatures. The chart of Fig. 49 shows the loss of heat through walls under moderate exposure to wind. The losses will be greater on northern and western exposures, because our cold winds are those from the north and west. You will also see from the chart that, if the difference between indoor and outdoor temperatures is doubled, the heat loss is doubled, or that the rate of heat loss through windows, doors, and walls is directly proportional to the difference between inside and outside temperatures.

54. Clothing. Besides the shelter of buildings, civilized man uses clothing for protection against the cold. If one wears summer-weight clothing in winter, one's body loses an excessive amount of heat and this loss of body heat must be made up by the use of more food. The value of clothing

as a heat insulator comes partly from the poor conducting property of the fiber itself and partly from the presence of air enclosed by the fibers. Wool fibers, because of their saw-tooth edges, when matted together, form many minute spaces for holding air; while cotton and silk, whose fibers have smooth surfaces, do not hold air as well. Fur and feathers protect animals against the cold largely because of the air enclosed and held stagnant. In hot weather the clothing should assist the body to lose heat. It should be a good conductor, as cotton and linen, porous to permit circulating air to reach the skin, and absorptive to take up moisture resulting from perspiration. Evaporation of moisture is a process which absorbs heat and is frequently a means of keeping one comfortably cool.

SUMMARY

1. Heat may be transferred from one place to another in three ways, conduction, convection, and radiation.

2. Heat flows from points of high temperature to points of low temperature by a process called **conduction.** In this process heat energy is passed along from particle to particle in the conducting body.

3. At temperatures below that of the body, good conductors of heat feel colder than poor conductors, because by conducting the heat away rapidly they maintain a greater difference in temperature between the object and the hand.

4. In **convection** there is an upward movement of the heated portions of liquid or gas, which mingle with the colder portions.

5. Heat is carried by **radiation** by means of ether waves, through some forms of matter and through space where there is no matter. It is by radiation that we receive heat from the sun.

6. Black, dull and rough surfaces radiate heat better than white, bright and smooth surfaces. Surfaces that radiate best also absorb heat best.

7. The materials used and the methods of construction of a house are important factors in determining loss of heat in winter or exclusion of heat in summer.

8. The rate of heat loss through the walls of a building are directly proportional to the difference between inside and outside temperatures.

9. Clothing with fibers like those of wool and fur, which enable it to hold much air within its meshes, is warm because heat passes through it with difficulty. In hot weather, evaporation of moisture should be aided by wearing absorbent, porous clothing, such as cotton and linen.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. Which is of more importance to us, heat conduction or heat insulation?
2. Conservation of heat.
3. Test sawdust, sand, loose cotton, paper, etc., for relative heat conductivity.
4. Compare the radiation and absorption by dull, black, rough surfaces with the radiation and absorption by bright, white, smooth surfaces.

REFERENCE BOOKS

Black. *Laboratory Experiments in Practical Physics.* The Macmillan Company.

Pye. *Heat and Energy.* Oxford University Press.

Smith. *Elements of Applied Physics.* McGraw-Hill Book Company.

CHAPTER VI

THE WEATHER

55. Influence of the weather upon us. Our casual remarks to our friends are oftener about the weather than about any other one thing. We say it is "sharp," "sultry," "sweltering," and, in so doing, we express a physiological effect which the weather has upon us. There is also a psychological effect, which we express when we speak of the weather as being "dull," "close" or "gloomy." Weather conditions are important factors in our homes. We regulate our heating devices according to the weather. The drying of clothes depends on the dryness of the air. An extended period of damp weather favors the molding and decay of foods and other materials. The shrubs, flowers and vegetables about the house, or in the garden, are chosen with due regard to the climate which results from all the weather factors.

56. The atmosphere. Weather is the condition resulting from many factors in our atmosphere. Heat, cold, moisture, dryness, sunshine, cloudiness, pressure, winds and electrical disturbances are the important variable factors in the atmosphere which determine our weather. The atmosphere, as you know, is the entire body of air which surrounds the earth. It is densest at sea level and loses rapidly in density with an increase in altitude. It is believed that the air extends to a height of more than one or two hundred miles above the earth, but more than half of it, by weight, is within four miles of earth's surface.

Since air has weight. it exerts pressure. As we ascend a high mountain, the depth of air above is diminished, and the pressure therefore decreases. The chart of Fig. 50 shows how the air pressure varies with the altitude.

The pressure of air is measured by finding how tall a column of mercury it will support. At sea level, the at-

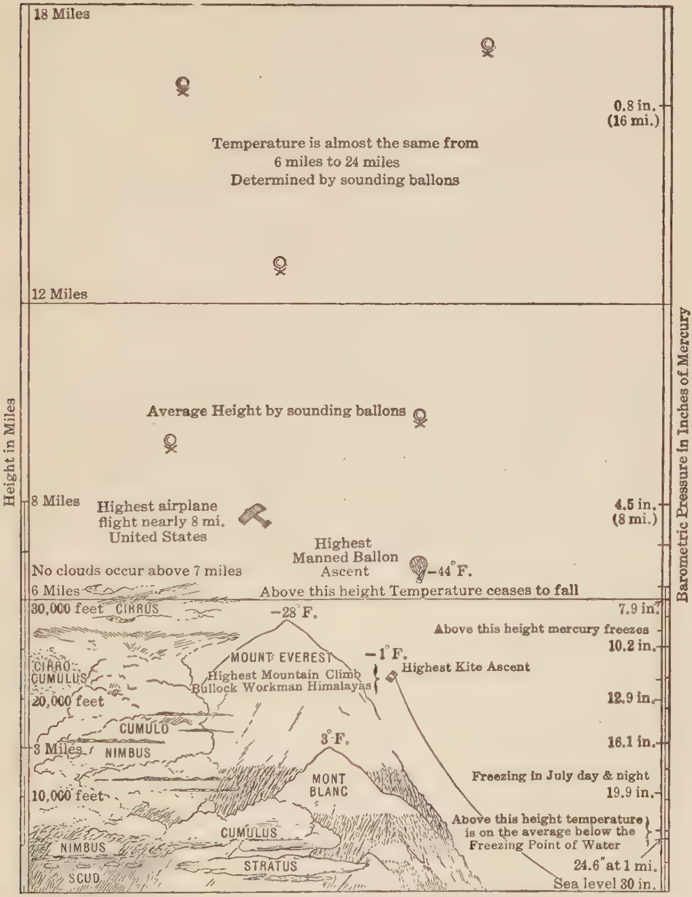


Fig. 50. — Explorations in our atmosphere: clouds, temperatures, and pressures at different elevations.

mosphere will hold a column of mercury about 30 inches high, and exerts a pressure of approximately 15 pounds per square inch. The pressure of the air can be measured ac-

curately by means of an instrument called a **barometer.** Barometer readings are of great value to the Weather Bureau in preparing its weather forecasts.

57. Experimental barometer. Fill a glass tube, about 35 inches long and closed at one end, nearly full of mercury. Cover the open end of the tube with the finger. Invert the tube and allow the large bubble of air to pass through the mercury to the opposite end of the tube. Slowly invert the tube again and let the air come back, gathering with it all the small air bubbles that were enclosed with the mercury. Fill the tube full of mercury. Close the open end with the finger, being careful that no air is left between the finger and the mercury, place the end under the surface of mercury in a small vessel, and remove the finger. When the tube is vertical, as in Fig. 51, the mercury will fall until its downward pressure is just balanced by the pressure of a column of air on the surface of the mercury in the vessel. When all the air is removed from the mercury in a barometer tube by heating to a high temperature, very accurate measurements of air pressure can be made.

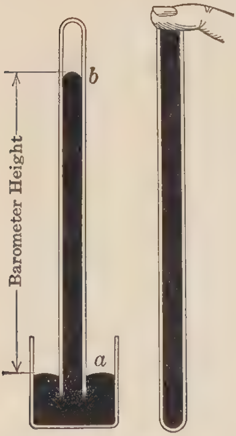
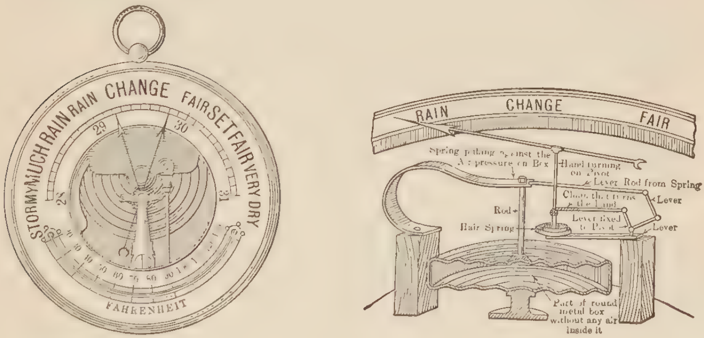


FIG. 51. — Principle of mercurial barometer.

There is always a vacuum in the tube at the top of the mercury column. A scale running from 28 inches to 32 inches above the mercury level in the reservoir makes it possible to observe the variations in the pressure of the atmosphere from day to day. At any given place the pressure of the atmosphere may vary by about 3 centimeters or a little more than 1 inch of mercury. The standard pressure, which is the average at sea level, is 29.92 inches or 76 centimeters. This is equivalent to a pressure of 14.7 pounds on every square inch of surface in contact with the air.

58. The aneroid barometer. The mercurial barometer is the standard weather instrument; but for many purposes, as in making a continuous record of the atmospheric pressure, in measuring heights of mountains, in getting data for contour maps and in registering the elevation of an airplane, a lighter and more compact instrument, such as the aneroid barometer, Fig. 52, is better. The aneroid barometer accomplishes the same purpose as the mercurial barometer, but it works on a somewhat different principle. The essential part is a thin metal box, with corrugated sides, from



(a) (b)

FIG. 52. — (a) Aneroid barometer. (b) Section of the same showing how motion of the side of the box causes pointer to move over dial.

which the air has been partly removed. This leaves less air pressure inside than outside the box, and as a result, the sides are forced inward. An increase in atmospheric pressure causes them to move still further inward, but upon a decrease in pressure the sides spring out. The actual amount of movement of the sides of the box is very slight, but by means of a series of levers the indicating pointer moves over a relatively larger space on the scale which indicates the pressure. The scale must be graduated by comparison with a mercurial barometer.

59. The sun as a factor in weather. Wind, temperature, and moisture in all its forms, are under the control of the sun. Whether we have skating or boating, skiing or baseball, in our northern states, depends upon the duration and intensity of sunshine. The intensity is greater under the direct or more perpendicular rays of the sun, which, for our latitude, are received when the sun is farthest north of the equator and the days longest. When days are short and nights are long, the earth loses more heat than it receives, and winter's snow and ice cover the earth. During the period of long days and short nights, more heat from the sun is absorbed by the earth than is given off, and so the earth is warmed and crops grow.

Clouds interfere with radiation. They prevent much radiation of energy from reaching the earth from the sun, and they also prevent the earth from losing heat by radiation.

60. Heat is a most important agent of weather. Heat is the one agent, above all others, which determines weather. Heat is involved directly in the temperature of the air. It also affects weather indirectly, by determining dryness, moisture, rain, wind, lightning, and frost. Since heat is directly responsible for the moisture of the air, it follows that it must be an important factor in the production of fogs, clouds, and precipitation.

61. Moisture in the air. We commonly speak of the air holding moisture, just as if the air could take up moisture and hold it in a sort of solution. This conception is easy to understand, but it is not scientifically correct. In fact, the amount of water vapor which will enter an enclosed space above the surface of water, at a given temperature, will always be the same, irrespective of the presence or absence of air in that space. See Fig. 53. The important thing that determines the amount of water vapor which will saturate a given space, is the *temperature*. The amount of water vapor in a given space depends also upon pressure,

but as the usual variation in pressure of the air is small, the effect of pressure is of little consequence.

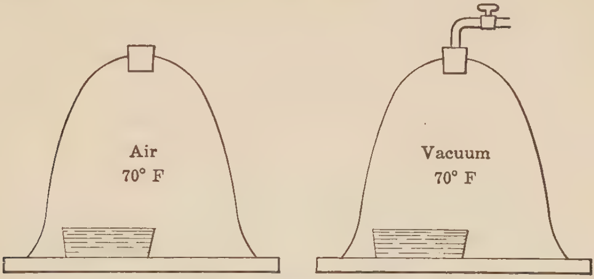


FIG. 53. — Under equal conditions of volume and temperature equal amounts of water vaporize to fill the space regardless of presence or absence of air.

62. Saturated air. Bodies of water, swamps, and forests are constantly losing water, which, in the vapor state, enters the surrounding air or space. There is, to some extent, a reverse action at the surface of the water, where moisture is passing back from the gaseous state to the liquid. When so much water vapor is present that no more can enter the

TABLE VII

WEIGHT OF WATER VAPOR REQUIRED FOR SATURATION AT DIFFERENT TEMPERATURES

English				Metric	
Temperature Fahrenheit	Grains of Water Vapor per cu. ft.	Temperature Fahrenheit	Grains of Water Vapor per cu. ft.	Temperature Centigrade	Grams per Cubic Meter
−20°	.21	65°	6.79	−20°	1.08
0°	.32	70°	7.98	−10°	2.36
10°	.78	75°	9.36	0°	4.84
20°	1.23	80°	10.93	5°	6.77
30°	1.94	85°	12.74	10°	9.33
40°	2.85	90°	14.79	15°	12.73
45°	3.42	95°	17.13	20°	17.12
50°	4.07	100°	19.76	25°	22.82
55°	4.85	104°	22.12	30°	30.04
60°	5.74			35°	29.23

air without an equal condensation, the **saturation point** has been reached. Table VII shows the weight of water, in grains, which will saturate one cubic foot of space or air at different temperatures.

Saturated air at any temperature, if warmed, becomes unsaturated and able to take up more moisture. Saturated air, when cooled, remains saturated, but loses a part of its moisture by its condensing into liquid. The temperature at which cooling air becomes saturated is called the **dew point.**

63. Humidity. The actual amount of water vapor in a unit volume of air is the **absolute humidity.** The ratio of the absolute humidity to the amount of water vapor required to saturate a unit volume of air at a given temperature is the **relative humidity.** Saturated air always has a relative humidity of 100 per cent, meaning that the air is 100 per cent saturated. Air which is saturated at 50° F., if warmed to 85° F., would be approximately four-twelfths or one-third saturated, and would have a relative humidity of 33 per cent.

64. Causes of condensation. Moisture in air is condensed when any cooling process lowers its temperature below its dew point. The cooling may be caused by: (1) mixing with cooler air; (2) radiating heat to cooler bodies nearby, as to the cold ground, bodies of water, and ice; (3) contact with colder bodies, as grass and stones, which receive a deposit of dew or frost; (4) expansion — rising air expands, and by this process is cooled 1 degree for every 185 feet.

65. Clouds and rain. Millions of tiny particles of water, either in liquid or in solid form, are produced by the condensation resulting from cooling below the dew point. If the temperature is below freezing, ice particles will result, taking beautiful crystal shapes, shown by snow flakes, Fig. 54. If the temperature is above freezing, the condensed particles will be liquid. A cloud consists of a multitude of these particles floating high in the air. Condensed moisture is heavier than air, and yet very tiny particles are buoyed up for a long time. There is, however, a gradual settling

of these particles. As they settle, they may enter warmer, unsaturated air, and there evaporate. If two particles touch each other, they may coalesce and form larger droplets. The particles may also be increased in size by continued condensation in saturated air. The larger the droplets become, the less their surface per unit of weight, and as a result they are less easily held by the air. In time they become so large that they fall as rain or snow.

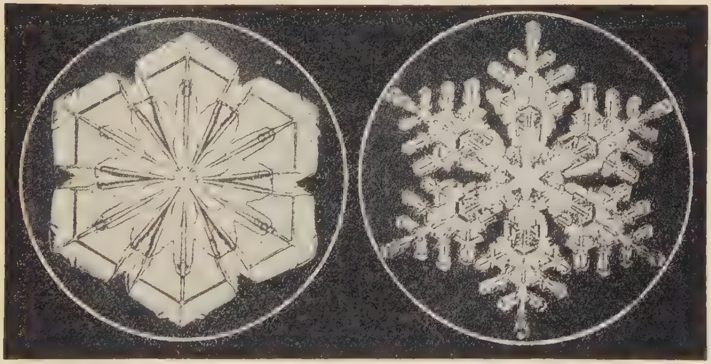
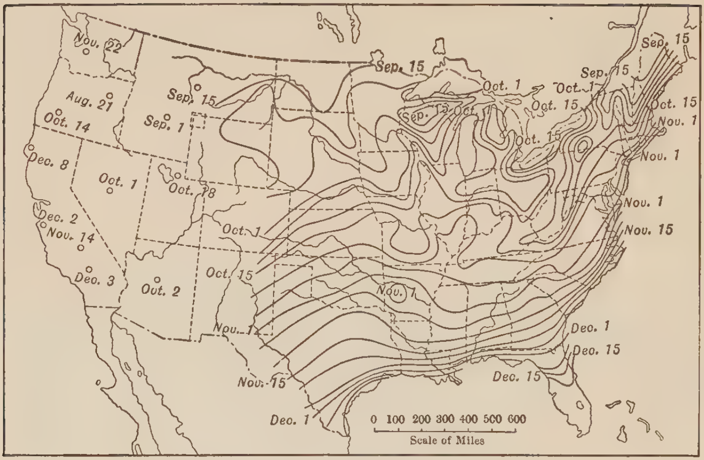
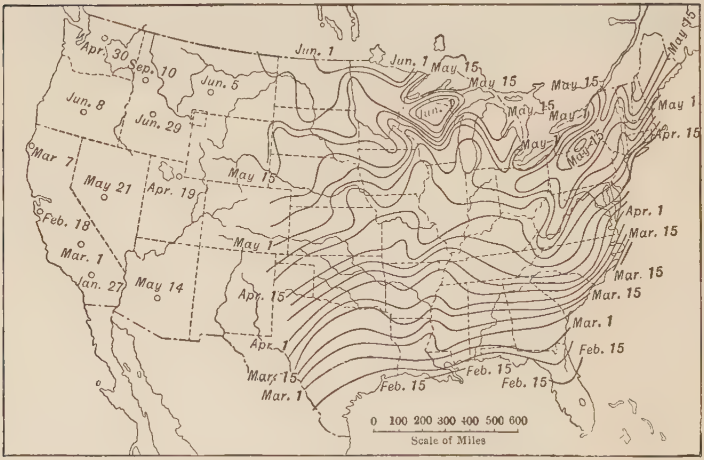


FIG. 54. — Water crystallized in snow flakes.

66. Dew and frost. As the earth radiates heat after the sun has set, grass blades and twigs, which are exposed to the air more than the earth itself, radiate heat faster, and become cooled to a lower temperature than the earth. Because of this, two hours after sunset the gravel walk may be 10 degrees warmer than the grass lawn beside it. If the air in contact with the grass is cooled until its humidity rises to 100, further cooling will result in condensation. The grass blades, twigs and plants, receive a deposit of dew sooner than rocks and sand, because they become cold sooner, and cause the air close to them to reach the dew point before the air in contact with rocks and sand does. If the temperature is below 32° F., a frost results instead of dew. For reasons given above, there may be a frost on the grass when



Average date of first killing frost in autumn.



Average date of last killing frost in spring.

FIG. 55. — The frost range in the United States.

there is none on the bare earth or on the gravel or cement walk.

When the air is still and there are no clouds, heat is radiated best. Thus it is that we have the heaviest dews or frost on still, cloudless nights. Since cold air is denser than warm air, it tends to flow into the valleys and upon the low land, lifting the warmer air, which may envelop the hills. For this reason we frequently hear of a frost on low land, on a night when there is no frost on high land nearby. Another reason for frost on low lands is found in the fact that frequently the low land is much wetter than the high land. The wet land will not get so warm during the day and will be colder at night.

Clouds prevent frost by preventing the loss of heat from the earth, by radiation. Winds prevent frost by diffusing warm and cold air, preventing the separation of air into layers of different temperatures. Plants and garden truck are saved from frost by covering with papers, cloths, or boxes, as this covering prevents the radiation of heat. Blossoms and fruit in apple orchards and orange groves are saved, in the West and South, by placing small pots of burning oil at short distances apart, throughout the groves. The smoke and moisture rising from the fires sometimes form a blanket over the grove, but direct radiation from the fires is depended upon, chiefly, to keep the temperature above freezing.

67. Fogs. A *fog* is in reality a cloud at the surface of the earth. When a fog is increasing in density the air is saturated and condensation is taking place. A person's clothes will become damp at such a time. This is called a **wet fog** and is likely to occur with a falling temperature. At other times a person may go into a fog without receiving any condensed moisture on his clothing. This is because the air during a rising temperature is unsaturated and the particles of moisture are being taken up by the air. This is called a **dry fog.** If the process continues long the fog will disap-

pear. Low clouds often disappear before one's eyes by a similar process.

68. Storms. Storms may be local, as the thunder storm and tornado, or widespread, as the more common cyclonic storm, which usually covers an area of several hundred miles. Cyclonic storms move across the continent from west to east, usually traveling a little toward the south in the Central United States, and working back toward the north in the East, see Fig. 56. Our cyclonic storms therefore leave the United States in a northeasterly direction. The center of

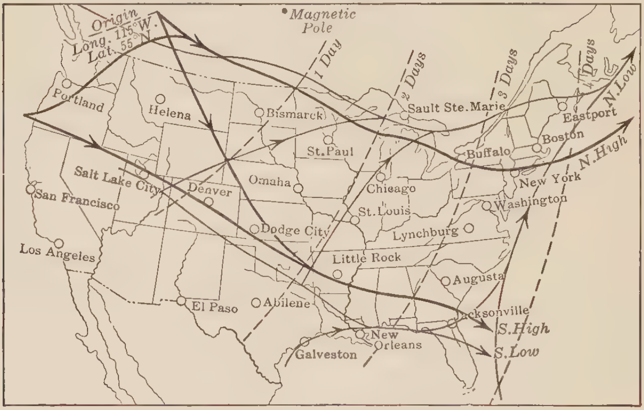


FIG. 56. — Storm tracks across the United States.

this storm area has low barometric pressure, and winds blow toward it from all directions. The warmest temperature is found at about the center of the low area. The southeast quadrant of this area is, as a rule, the one that gives the greatest rainfall or snow. The northwest quadrant is the one that gives us a cold temperature. A study of the diagram of the storm area, and its path across the continent, will explain why a falling barometer is an indication of a probable storm; why it is warmer during a storm and colder after it; why a rising barometer indicates probable fair weather; why an east or southeast wind indicates a

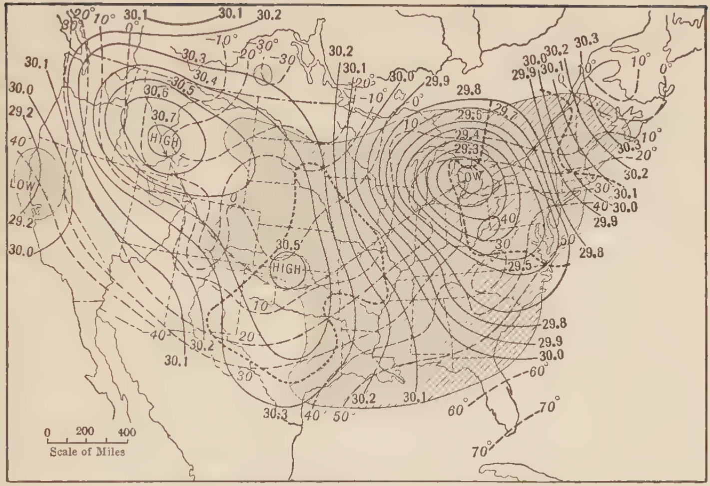


FIG. 57. — Weather map, Feb. 1. Note positions of low and high areas. Shaded areas have had rain or snow.

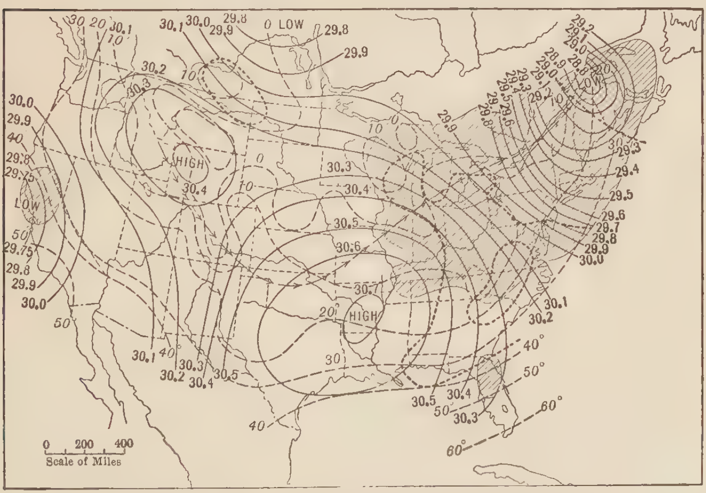


FIG. 58. — Weather map, Feb. 2. Note changed positions of lows and highs. The arrows indicate the path of the low.

storm; and why a northwest or west wind indicates clearing or fair weather.

69. Anticyclones. Alternating with the low pressure areas of the cyclonic storms, or **cyclones,** are areas of high pressure, which are called **anticyclones.** Conditions in

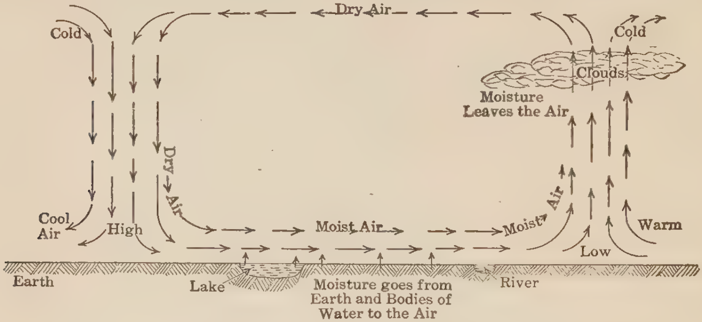


FIG. 59. — Circulation of air in "high" and "low" areas.

these areas of high pressure are contrasted with those of the low-pressure areas in Table VIII.

TABLE VIII

CYCLONES AND ANTICYCLONES

Weather factors	Cyclones	Anticyclones
Temperature........	Warm	Cold
Moisture............	Moist air	Dry air
Density.............	Light air	Dense air
Pressure............	Low	High
Wind................	Blows inward	Blows outward
Air current..........	Ascending	Descending
Sky.................	Cloudy	Clear

70. Snow and hail. When clouds result from condensation of moisture at a temperature below freezing, the vapor forms a characteristic six-angled snow crystal, and groups of these unite to form snow flakes. Rain drops formed in clouds at very high levels may drop through alternate

layers of warm and cold air and receive successive coats of ice. The hail stones thus formed frequently do much damage to crops.

71. Thunder storms. Thunder storms, unlike the storms which prevail through the larger portion of the United States, are local disturbances, being usually only a few miles in extent, and rarely covering an area with a 40-mile diameter. They occur when a land surface becomes excessively

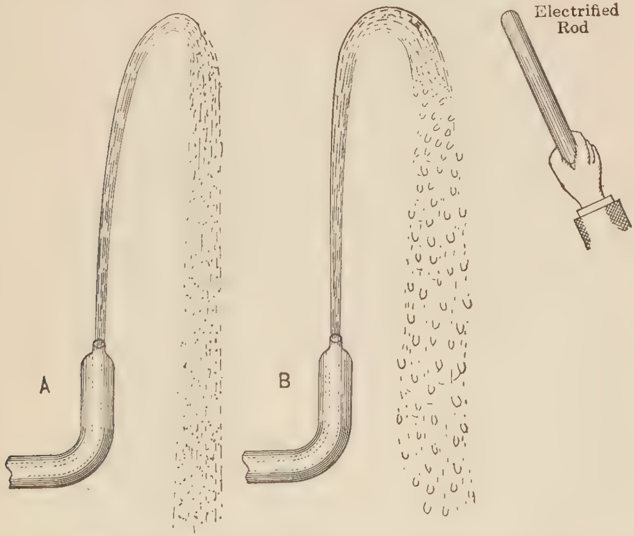


Fig. 60. — When a spray of water is electrified the drops increase in size.

hot. The air heated by the hot land rises in rapid currents, forming dense cumulus clouds which are forerunners of thunder storms. Very strong winds develop and usually a heavy downpour of rain follows, accompanied by electrical discharges.

You have doubtless observed that rain drops are much larger during a thunder storm than during other storms.

Drops of water, when electrified by induction, attract each other, and so a number of small drops unite to make one large one. This fact is easily demonstrated by sending a jet of water half-way to the ceiling, having it so placed that it falls into the sink. Adjust the flow of water to get a spray of fine drops. Electrify a rod of hard rubber with fur or flannel. Hold the electrified rod near the stream of rising water, as in Fig. 60. Instantly the drops increase in size very noticeably.

72. Lightning. Lightning is the characteristic accompaniment of thunder storms or electric storms. Clouds become charged with electricity, sometimes positively and sometimes negatively. The electric charges in two oppositely charged clouds, or in a cloud and the earth, attract each other, and if there is sufficient electrical pressure to overcome the resistance of the air between them a discharge takes place. In its passage through the air the electrical energy heats the air particles until they give light. This is the *lightning*. The heat causes the air to expand. After the flash and the accompanying heat and expansion, the air cools quickly and produces a partial vacuum. The greater pressure of the surrounding air forces air particles into this vacuum with great violence. The sound which is produced when these particles from opposite sides meet is *thunder*. One part of the lightning may be a mile away from you while the other part is nearby. The thunder from the more distant part will reach you about five seconds later than that from the nearer part. Thus while the flash of lightning is practically instantaneous, the thunder which you hear may be of considerable duration. Thunder may be reflected from the clouds, the ground, and layers of air of different density. Thunder from a series of discharges may overlap. Reflection and overlapping produce a characteristic rumbling, with which you are familiar.

73. Tornadoes. Another hot-weather storm is the *tornado*, sometimes improperly called a "cyclone." With the

possible exception of lightning, a tornado is the most violent of our atmospheric disturbances. It is even more local than the thunder storm, as it usually travels in a path but a few hundred feet in width. Air rises spirally at its center and flows in toward the center with high velocity, sometimes reaching several hundred miles per hour. The intense, whirling, upward current produces a partial vacuum at the center of the rising column. Moisture condenses and produces what appears as a funnel of cloud, sometimes reaching from the earth to the clouds above. The pressure within this funnel cloud may be reduced to 11 pounds per square inch, or nearly to 1600 pounds per square foot. This is a little over 500 pounds less than the normal atmospheric pressure. Picture your own house suddenly enveloped by the funnel cloud. The pressure of the air within the house is 2100 pounds per square foot. In an instant the pressure outside is reduced to 1600 pounds per square foot. This means that an unbalanced outward pressure of 500 pounds per square foot would be applied to the walls. If one side of the house were 20 by 30 feet — 600 square feet — the pressure on that one side would be 150 tons and the result would be in the nature of an explosion.

74. Advantages of variable temperatures. How often we hear someone complain about the frequent changes in temperature! If we were sure the temperature would not change we could provide clothing and shelter which would always make us comfortable. We long at times to live in a climate of even temperature. Studies of the civilization in countries where uniform temperatures are found indicate that even there conditions are not all that could be desired. The monotony of changeless temperature is very depressive. Prolonged uniform temperatures decrease one's ability to do efficient work, while a variable climate is found to promote both mental and physical efficiency. A drop of 4° F. is sufficient to stimulate one to greater activity. It has been found that women are more sensitive to changes in

temperature than men. A fall of 8° produces the same stimulation in women as a fall of 10° does in men. Circulation of blood is essential to all activities. Cold baths, hot baths, and alternation of hot and cold wet cloths are found to stimulate blood circulation. It is thought that in some way alternations in temperature increase our activity and so promote efficiency.

75. Relation of climate to latitude and altitude. As a rule, we consider that a cold climate belongs to polar re-

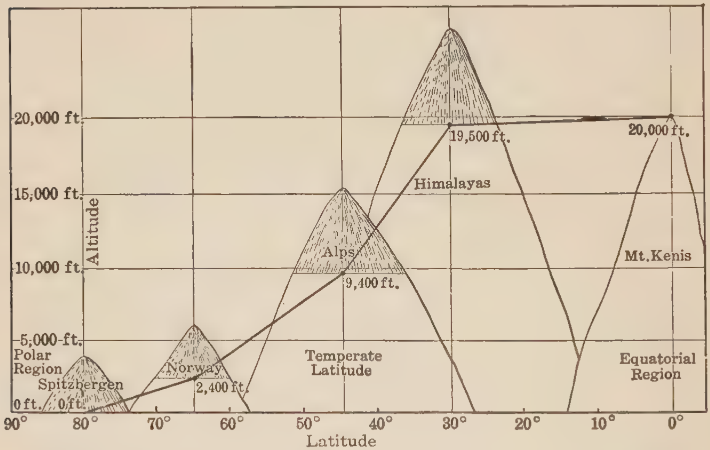


Fig. 61. — Altitude of perpetual snow line for different latitudes.

gions, and a hot climate to the tropics. On the whole this is true, but it is not the whole truth, for within the area of the Torrid Zone, covering a band around the earth more than 3000 miles broad, are found all types of climate. Within this belt are the driest, as well as the most humid areas in the world. Within this area, too, the temperature may vary from severe cold to intense heat. The tops of some of the mountain peaks reach a line of perpetual snow, while at low altitudes we find the hottest temperatures of any place on the earth. An altitude of 300 feet at the equator means

a drop of about 2 degrees in temperature, and is equivalent to moving north, or south, 140 miles. It is not even true that all the Arctic Zone is a land of perpetual snow, and at a latitude of 65 degrees in Alaska, within 2 degrees of the Arctic Circle, wheat, alfalfa, and vegetables, such as cabbages, peas, and turnips, are successfully grown.

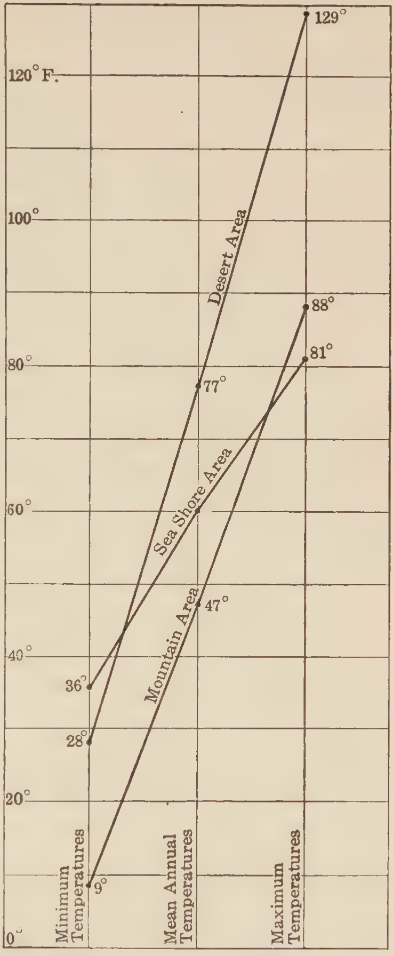


Fig. 62. — Range of temperatures in three typical regions.

76. The effect of bodies of water upon climate. The high specific heat of water gives a body of water a large heat capacity, and, as a result, lakes and oceans store vast quantities of heat energy received from the sun. Under favorable conditions this heat is given to the air, and in this way tempers the climate. In some parts of the earth, alternating land breezes and sea breezes result from the differences in temperature of water and land areas. Because the earth is warmed to a higher temperature than water by a given quantity of heat, the air over the land becomes hotter than the air over the water during the day time,

and the cold air from the water flows in over the land, pushing the lighter, warm air upward. The warmed land radiates heat faster than the cooler water, and as a result the land, even though hotter than the water, contains less stored energy. At night the earth, since it has less stored heat than the water, cools faster and becomes colder than the water. This results in a flow of air from land to water. In freezing weather the water gives up heat to the air, not only in cooling but also during the process of freezing. The formation of one pound of ice liberates as much heat as the cooling of 144 pounds of water 1° F.

In San Diego County, California, are to be found mountain, desert, and seacoast areas adjoining one another. The mountainous region has low humidity, cool winters and warm summers, with wide variation between day and night temperatures. The seacoast region has moderately high humidity, warm winters, and cool summers, with slight variation between day and night temperatures. The desert region has warm winters, with wide variation of day and night temperatures, hot summers with little variation of day and night temperatures, and extremely low humidity.

SUMMARY

1. Weather is the resultant of various factors acting in the atmosphere, chiefly under the influence of the sun — which is the source of all energy on the earth.

2. The normal pressure of the atmosphere is 14.7 pounds per square inch.

3. The barometer is an instrument for measuring the pressure of the atmosphere. The mercurial barometer uses a column of mercury which is supported by the atmosphere, and the aneroid barometer records the pressure that the atmosphere exerts upon a metal box from which the air has been partly removed.

4. Barometers for measuring atmospheric pressure are useful in weather forecasting and in measuring altitude.

5. "Saturated air," meaning saturated space, exists when a given space holds all the moisture it can hold at a given temperature. The capacity of the "air" (space) for holding moisture increases with a rise in temperature.

6. The actual amount of water vapor (grains per cubic foot) in the air is the **absolute humidity.** The ratio of absolute humidity to the capacity of the air at a given temperature, expressed in per cent, is the **relative humidity.**

7. Clouds are formed by condensation of moisture in air through cooling. Dew and fogs are formed in a similar way near the earth's surface. Snow and frost occur when the condensation takes place below the freezing point.

8. Cyclonic storms travel across the country periodically, alternating with anticyclones, or periods of clear weather. Thunder storms are local storms attended with electrical discharges. Tornadoes are storms of very limited extent, but of exceptional violence, due to the extremely low barometric pressure at the center of the funnel cloud.

9. Variable temperatures are considered better than uniform temperatures, both for health and for efficient work.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. The local weather station.
2. Weather facts and weather fallacies.
3. Electrical storms and protection against lightning.
4. Measure the height of a school building or a near-by hill with an aneroid barometer.
5. Measure the humidity of the air in the room.

REFERENCE BOOKS

HUNTINGTON. *Civilization and Climate.* Yale University Press.

JAMESON. *Weather and Weather Instruments.* Taylor Instrument Company.

JAMESON. *The Barometer as the Foot-rule of the Air.* Taylor Instrument Company.

JAMESON. *Humidity.* Taylor Instrument Company.

Jameson. *The Mountains of Cloudland, and Rainfall.* Taylor Instrument Company.

Jameson. *Practical Hints for Amateur Weather Forecasting.* Taylor Instrument Company.

Packard. *Everyday Physics.* (*Humidity, page* 30.) Ginn and Company.

Shaw. *The Air and its Ways.* (Technical) Cambridge University Press.

Whitman. *Lightning.* In General Science Quarterly, November, 1916.

CHAPTER VII

BOILING WATER AND STEAM

77. Boiling water. No process used in the kitchen is more common than that of boiling water. We have already seen that the temperature of the water rises when water is heated. Let us now make a more careful study of this process. Fill a 1-liter beaker three-fourths full of water from the faucet. We shall use glass in order that we may watch what goes on, and thin glass lest the heat crack it by unequal expansion. Place the beaker over a gas flame, suspend a thermometer in it, and watch for results. You will notice first that small bubbles of gas separate from the water, and many of them cling to the walls of the beaker. They are bubbles of air which had previously dissolved in the water. Their removal from the water causes the "flat, insipid taste" in freshly boiled and distilled water. After a time larger bubbles appear at the bottom of the flask. They start to rise and quickly disappear. Now these bubbles rise higher and higher, starting large and growing smaller until they, too, disappear. Soon we see vapor escaping from the surface of the water. We hear a sound which, when produced in the tea-kettle, is spoken of as "the singing of the kettle." The mercury in the thermometer has been rising all this time, but the temperature has not yet reached 200° F. The bubbles which rise from the bottom of the beaker are bubbles of steam. In rising they meet cold water, which causes them to condense, and as they disappear, the water coming together in the space which they occupied strikes many small blows, which cause the "singing" sound. Before long we see that a few bubbles actually reach the surface of the water, then more and more

of them. As the bubbles now rise, they increase in size as they near the surface. The bubbles are not condensed any longer because the water and the steam are at the same temperature. They increase in size as they rise because the pressure of the water upon them grows less as they near the surface. As the bubbles break through the surface of the water, they produce the effect of *boiling*. These bubbles are steam, which is water in the form of gas. When the entire surface is bubbling from the escape of steam, the thermometer registers 212° F. We continue to apply the heat, and no other effect on the water is observed unless it

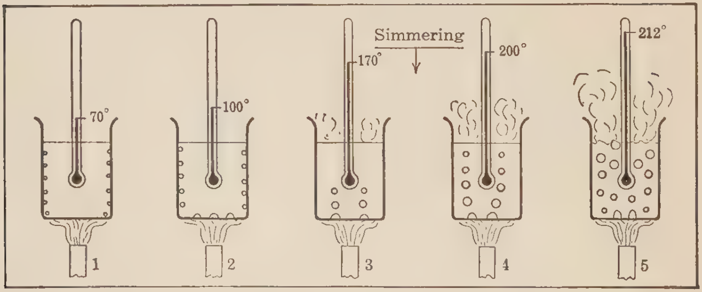


FIG. 63. — Boiling water. After reading the text, tell just what is taking place in each of these five drawings.

be more vigorous boiling. The temperature remains unchanged. No matter how long we boil the water, it will get no hotter, so long as we let the steam escape freely. This temperature, 212° F., is the **boiling temperature** of water.

78. Relation of the boiling point to pressure. In order to escape as gas, the steam must push the air aside. What would happen if there were less air and so less pressure on the surface of the water? What would happen if the steam were held back by a tight cover which increased the pressure? Would the steam go off just the same and would the boiling temperature be the same?

We have already learned that the normal atmospheric pressure at sea level is about 15 pounds to the square inch and that on high mountains and other high elevations the pressure is less. The pressure upon the surface of water which we are heating may be increased by preventing the escape of steam. Decreased pressure may be obtained by going to a higher elevation or by pumping out the air and steam. We can easily learn the relation between the boiling temperature and pressure by the demonstration which follows:

Heat water in a strong glass flask, fitted with a thermometer, pressure gauge, and outlet tube, as shown in Fig. 64. When the thermometer indicates 180° F. (80° C.), attach the rubber tubing to an exhaust pump or aspirator, to lower the pressure on the surface of the water. Observe the difference in mercury levels in the pressure gauge, and also note the temperature when the water boils. Disconnect the exhaust pump and continue heating until boiling begins. Have you observed that you cannot see the steam in the flask? Steam is invisible. Boil the water slowly. When the mercury columns are at the same level, read the thermometer. This reading is the boiling temperature for the atmospheric pressure at the time. Read the barometer to learn what this pressure is. Now partly close the pinchcock so that steam cannot escape as fast as it is generated. When the temperature reaches 220° F. (105° C.), measure the difference in mercury levels in the gauge tubes. Remove the flame at once.

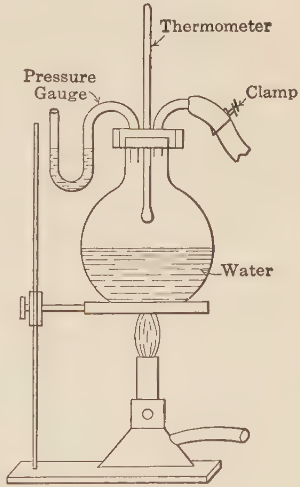


FIG. 64. — Apparatus for showing the relation of boiling point to pressure.

The boiling point of water at different pressures has been carefully determined by experiments, and the results are given in Table IX.

TABLE IX

THE BOILING POINT OF WATER AT DIFFERENT PRESSURES

Pounds per sq. inch	Barometer reading in Cm.	Boiling Point	
		Centigrade	Fahrenheit
Lbs.	Cm.	Degrees	Degrees
1.00	5.17	39	102
7.35	38.00	81	178
10.00	51.70	90	193
14.13	73.00	98.88	210
14.32	74.00	99.26	210.7
14.51	75.00	99.63	211.3
14.70	76.00	100	212
14.89	77.00	100.37	212.7
15.08	78.00	100.73	213.3
20.00	103.40	109	228
30.00	155.10	121	250
40.00	206.80	131	267
50.00	258.50	138	281
250.00	1292.50	208	406

The curve of Fig. 65 shows the rapid rate at which the temperature rises with increase of pressure.

79. Boiling under normal pressure. Much cooking is done in boiling water, in vessels which are open or loosely covered, so that the temperature of the water is around 212° F. When cold, raw food is put into boiling water, it absorbs heat and the water is cooled. A cold egg dropped into a cup of boiling water on the stove will stop the boiling and reduce the temperature several degrees. When cereals are cooked in boiling water, thickening prevents convection and increases the danger of burning. For such cooking, the double boiler is useful. Steam has the same tempera-

ture as the boiling water from which it comes, and since a large part of the food compartment of the boiler is surrounded by steam, it is almost as hot as if the contents were actually boiling. The double boiler is a type of steam cooker.

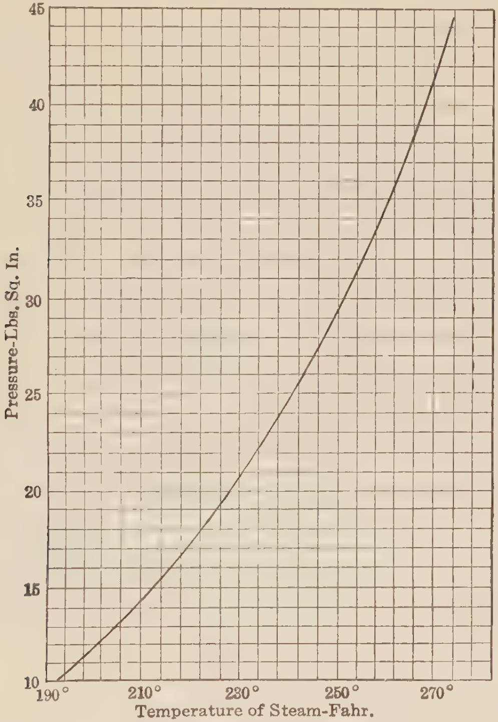


FIG. 65. — Relation of the boiling temperature of water to pressure.

80. Boiling under low pressure. No practical use is made in the household of boiling at pressures below normal, and yet we use products which have been prepared under low-pressure boiling temperatures. One of our staple foods, sugar, is crystallized from solution in huge vacuum pans. It is impossible to drive the water off at normal pressure without changing some of the sugar chemically. When

the pressure on the solution is reduced to one-half an atmosphere, water will boil at 178° F. The temperature of the solution in the vacuum pans is kept at about 150° F. to 160° F. by regulating the amount of vacuum. Condensed milk and evaporated cream are food products prepared by evaporating some of the water from skimmed milk and milk, respectively, in a partial vacuum. Boiling milk under normal conditions would change the composition

Fig. 66. — Vacuum pans in which water is removed from sugar by boiling under reduced pressure.

and the taste of the milk much more than boiling it at a lower temperature under reduced pressure. The removal of water from other foods is sometimes accomplished quickly at high temperatures, or more slowly under reduced pressures. Egg-powder, milk-powder, and dehydrated vegetables are products from which the water has been removed as a means of preserving them.

81. The steam cooker. Many vegetables and meats are cooked in water, steam, or water and steam, at 212° F. The

steam cooker is a very efficient device for cooking. A food may be cooked in steam as effectively as in water, with the advantage of losing less of the extracts, which would dissolve if cooked in water, and with less danger of sogginess in starchy foods. In the steam cooker, water is in the bottom compartment, which sits upon the stove. The steam rises and may pass through several compartments which contain different foods. The cooker is tightly covered, so that very little steam escapes. After the cooker and con-

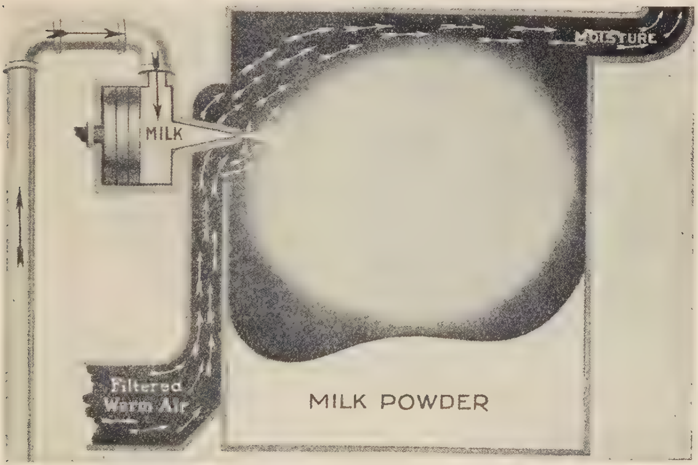


Fig. 67. — Milk powder is produced by vaporizing the water in a chamber through which a stream of warm air is constantly moving. The milk is introduced as a fine spray of vapor.

tents are once heated to the temperature of steam, it requires very little fuel to keep the contents cooking. Steam must be produced fast enough to replace that condensed on the walls of the cooker, and to give up enough heat to make up for what is lost by radiation, conduction, and convection from the outside surface of the cooker. But there is much less waste of heat from escaping steam than there is when boiling is done in an open or loosely covered kettle.

82. The pressure cooker. Boiling water has a temperature of 196° F. on Pike's Peak and of 202° F. in Denver. It requires a longer time to cook vegetables and meats in boiling water at high elvations than it does at sea level. It is therefore advantageous, in high altitudes where the pressure is low, to cook vegetables and meats under pressure, although at lower altitudes these foods would be cooked in boiling water or free steam. When a vessel containing boiling water is closed to prevent the escape of steam, great pressure results and a rise in temperature follows. Such devices, called *pressure cookers*, are frequently used to secure a higher temperature of boiling. At 5 pounds pressure (above atmospheric pressure) a temperature of 228° F. is obtained; at 10 pounds, 240° F.; and at 15 pounds pressure, 250° F. Not only does this cooker find favor in high altitudes, but in any section of the country it enables us to cook foods more quickly, with a consequent saving of fuel. Certain tough cuts of meat, which are not desirable food when cooked at 212° F., are tender and palatable if cooked at the high temperature obtained under 15 to 20 pounds pressure.

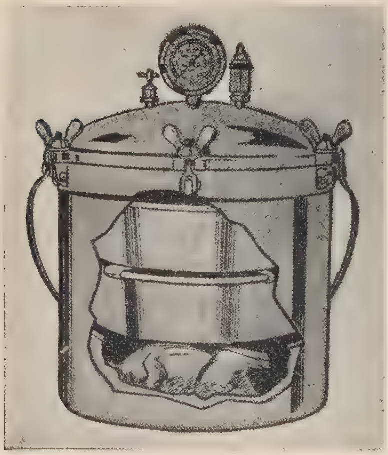


FIG. 68. — A pressure cooker.

Another useful application of the pressure cooker is in canning fruits and vegetables. Most vegetables and some fruits are scalded or blanched in boiling water, and then dipped into cold water. They are then canned and placed in the pressure cooker. Asparagus requires 40 minutes

cooking under 5 pounds pressure or 30 minutes under 15 pounds pressure. Peaches require 10 minutes at 5 pounds and 5 minutes at 15 pounds pressure. Sterilizing can be done more efficiently at the high temperature of the pressure cooker. The extraction of gelatin and glue from bones is accomplished under a pressure of 10 to 20 pounds, in extractors which are in principle like the pressure cooker.

The time-saving value of the pressure cooker is shown by Table X.

Table X

TIME REQUIRED TO COOK FOODS

	Open Vessel Cookery	Steam Pressure Cookery
Pork and Beans	3 Hrs.	40 Min.
Ham	4 Hrs.	50 Min.
Pot Roast	2 Hrs.	50 Min.
Meat Soups	2 Hrs.	30 Min.
Chicken	90 Min.	30 Min.
Cabbage	40 Min.	10 Min.
Potatoes	30 Min.	10 Min.
String Beans	50 Min.	15 Min.
Steamed Puddings	30 Min.	10 Min.
Oatmeal	90 Min.	30 Min.

83. Coffee percolator. The coffee percolator owes its geyser-like action to the production of steam under greater than normal pressure. It is a geyser in miniature, and is as regular in its periodic spoutings as the natural geysers themselves. One often wonders to see the action begin within a minute after heat is applied and while the water is still cold. Close study of the parts of the percolator, Fig. 69, explains this action. A small body of water is separated from the rest in a reservoir at the bottom of the percolator. A tube extends from the top of this chamber to the space above the coffee at the top of the percolator. Water in the chamber receives direct heat and keeps it, since, enclosed as it is, it cannot set up convection currents

throughout the entire liquid. For this reason, boiling water is produced in the enclosed chamber, while the outside water is comparatively cold. The column of water in the tube causes sufficient pressure to raise the boiling temperature a little above the normal boiling point. In some percolators there is a valve to the percolating chamber. When steam forms, it exerts pressure which closes the valve, and then the only escape is through the tube; but this tube contains water, which is forced out by the steam. As soon as this happens the pressure is reduced; then the pressure of the water on the outside of the valve opens it, and the percolating chamber is filled with water again. The heating of this water and the resulting flow from the tube are repeated periodically. Some percolators have no valve, but have a very small inlet for the cold water to enter. In the rapid movement of water when steam is suddenly produced in quantity, very little of it escapes from the chamber through the small inlet spaces, while the greater part of it is blown up through the tube.

FIG. 69. — Coffee percolator, showing the pumping unit where heat makes steam intermittantly to raise the water in the tube and spray it over the coffee placed in the receptacle at the top.

84. Other uses of steam under pressure. There are clothes washers which work on about the same principle as the coffee percolator. These washers are placed in a wash boiler and the clothes placed around them. The action of the washer is sufficient to cause the circulation through the clothes, by which means the clothes are cleaned. In steam heating there is usually some pressure in the boiler in excess of the atmospheric pressure. The temperature

of the steam in the radiator is determined by this pressure; likewise the power stored in steam, which operates the steam engine, depends upon the temperature of the steam, or the pressure at which it leaves the boiler.

85. Boiling temperatures. Every liquid has its own definite boiling point, which differs from those of other liquids. The boiling point of sugar sirup is higher than that of pure water. When salt is dissolved in water, the solution has a specific boiling point, depending upon the strength of the solution. A saturated solution of common salt boils at 109° C. (228° F.), and a strong solution of calcium chloride boils at 135° C. (275° F.). Extracts and fats from meat raise the boiling temperature of the liquid in the preparation of a broth or a stew.

TABLE XI

BOILING POINTS

Liquid air	− 190° C.	Water	100° C.
Liquid ammonia	− 38.5° C.	Turpentine	160° C.
Ether	35° C.	Glycerine	290° C.
Alcohol	78° C.	Mercury	357° C.

86. Vaporization and evaporation. Vaporization is a term applied to the process of changing from the liquid to the gaseous state. Water vaporizes during the boiling process; it also vaporizes to some extent at all temperatures. When water or any other liquid changes to a gas at a temperature below its boiling point, the process is called **evaporation.** Evaporation can take place only at the expense of heat energy. The higher the temperature, the greater the amount of the evaporation. Since pressure on the surface tends to prevent the passage of molecules of liquid from the surface, it follows that increasing the pressure lessens, and decreasing the pressure promotes, evaporation. Evaporation is greater from a large than from a small surface. The degree of saturation of the air above the liquid also influences the rate of evaporation. Moving air removes moisture and

brings less-saturated air in contact with the surface of the liquid, and so a wind promotes evaporation. Clothes on the line dry quickly on a windy day, as do also wet pavements. Evaporation will take place even at temperatures below the freezing point of water. A block of ice is found to diminish in weight even if kept at a temperature below zero Centigrade, and it is a common experience that clothes hung on the line in cold weather freeze and dry without thawing.

87. Dehydration. The preservation of foods by removal of water has been practiced for centuries. Foods dried over six thousand years ago in Egypt have been found perfectly preserved. The process of preparing dried or "evaporated" foods is commonly carried on at ordinary temperatures and pressures, but with relatively dry air. This process damages the delicate fibers and food tissues, so that toughness, flatness of taste, and some loss of food value result. An improved method of taking the water out of foods, especially fruits and vegetables, is known as **dehydration.** In this process the fruit or vegetables are subjected to the action of moving hot air, which has a predetermined amount of moisture in it. Under the action of the heat in the presence of the moist air, the water leaves the cells of the food without injuring the tissues or destroying the flavor. Dehydration is an improvement over ordinary drying because, when water is supplied to the dehydrated food, it regains its original appearance and flavor to a much greater degree than do dried foods.

88. Heat of vaporization. We have seen that when water is at the boiling temperature, additional heat does not increase its temperature; instead, it increases the internal molecular energy and causes the liquid to change to a gas. The resulting steam has the same temperature as the boiling water. It is possible to find approximately the amount of heat absorbed in this change of state by the following experiment. Secure two dishes of the same kind and size, holding about half a liter. Pour into one 20 grams of water

at 20° C., and pour into the other 300 grams of water at the same temperature. Place these dishes on the stove at the same time, so that they will receive equal amounts of heat. Stir the 300 grams of water at intervals with a thermometer. Do not let the thermometer bulb rest on the bottom of the dish at any time. At the very instant that the 20 grams of water has entirely vaporized, take the temperature of the 300 grams of water.

In one experiment the temperature of the 300 grams of water rose from 20° C. to 61° C. The amount of heat absorbed was $300 \times 41 = 12{,}300$ calories. If we may assume that both bodies of water received equal quantities of heat, then the 20 grams of water has absorbed 12,300 calories, but it has absorbed them in two processes: (1) in being warmed from 20° C. to 100° C.; (2) in changing from water into steam at 100° C.

In changing from 20° C. to 100° C., $20 \times (100 - 20)$ or 1600 calories were absorbed. There remain $12{,}300 - 1600$ or 10,700 calories, absorbed in the process of changing state. One gram of water would then have absorbed $10{,}700 \div 20$ or 535 calories. Different experimenters have obtained different numbers, ranging from below 534 to above 540 calories. Let us take an average, say 537 calories, as the amount of heat required to change one gram of water at 100° C. into steam at 100° C.

The heat of vaporization of water is 537 *calories per gram.* In English units, the heat of vaporization is 965 *B.t.u. per pound.*

Whenever one gram of steam condenses at 100° C., it gives up 537 calories of heat, and the resulting water is at the same temperature as the steam. This explains why a burn by steam is so much more severe than one by hot water. As long as steam remains in a gaseous state it holds the heat of vaporization stored in it. This makes it practical to use steam in heating distant rooms. It is only necessary to allow the steam to condense in the radiator in the room to be heated, and this latent and stored heat will be given up.

PROBLEMS

1. How many B.t.u. will be liberated in a radiator by the condensation of 15 pounds of steam?

2. How many calories are required to change 25 grams of water at 40° C. into steam at 100° C?

3. Compare the quantities of heat set free
   (*a*) When 10 grams of water at 100° C. are cooled to 80° C.
   (*b*) When 10 grams of steam at 100° C. are changed to water at 80° C.

How do these results explain the relative severity of burns received by hot water and by steam?

SUMMARY

1. Evaporation is the change of a liquid to a gas, at the surface of the liquid. Boiling is the change of a liquid to a gas within the liquid, so that bubbles of gas must rise through the liquid to escape.

2. The boiling point of a liquid is the highest temperature to which the liquid can be warmed without increasing the pressure upon it. At this temperature it passes rapidly into the gaseous state.

3. The boiling point of a liquid is lowered by a decrease in pressure, and raised by an increase in pressure.

4. Steam has the same temperature as the water from which it comes. Steam is a valuable cooking agent in the steam cooker, double boiler, and pressure cooker.

5. The coffee percolator makes use of the pressure of confined steam to force the jets of water over the coffee, through which it sinks, taking with it the soluble extracts.

6. Dehydration is the process of removing water from foods without injuring the tissues and without destroying the flavor. It is an improved method of drying foods.

7. It requires 537 calories to change one gram of water at 100° C. to one gram of steam at the same temperature. In other words, 537 calories is the heat of vaporization of water.

8. The liberation of the heat of vaporization, when steam condenses, makes possible the use of steam in our steam heating systems.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. Cooking with steam.
2. Domestic and commercial canning
3. Determine the heat of vaporization of water.
4. Operation of different types of coffee percolators.

REFERENCE BOOKS

BLACK. *Practical Physics.* The Macmillan Company.
BLACK. *Experiments in Practical Physics.* The Macmillan Company.
HENDERSON. *Physics in Everyday Life.* Lyons and Carnahan.
LYNDE. *Physics of the Household.* The Macmillan Company.

CHAPTER VIII

HEAT FOR COOKING PURPOSES

89. The coal range. The ordinary kitchen range for burning coal has a small *fire-box* lined with fire-clay, an *ash pit*, and an *oven*. The burning of the fuel is regulated by controlling drafts and dampers. The main air supply enters through the draft into the ash pit under the coal, and passes through the layers of coal, where it aids combustion. The hot gases, coming from the burning coal, pass directly to the chimney through the stovepipe, or around the oven and then to the chimney. There is a *check draft* which admits air directly to the fire-box above the coal. A *damper*, and frequently a check draft, which may be used to check the fire, is placed in the stovepipe. An *oven damper*, if raised, causes the hot gases to pass around the oven before entering the stovepipe. When the oven damper is down, the hot gases pass directly to the stovepipe. Much cooking is done on

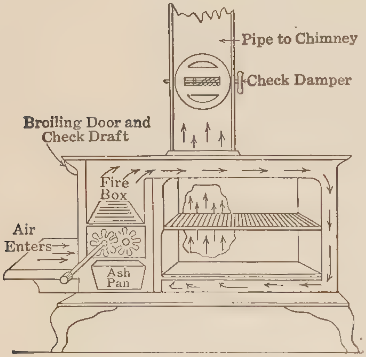


FIG. 70. — The coal range.

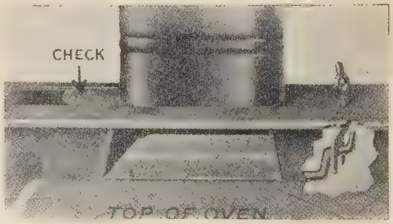


FIG. 71.— Close this damper for baking.

top of the stove. Covers can be removed and a vessel placed directly over the burning fuel to secure quicker heating or a hotter temperature. A long, narrow door at the side and top of the fire-box may be opened for the purpose of broiling.

90. Oven temperature. The oven is heated by hot gases, which are compelled to encircle it. The oven temperature may easily be regulated by the strength of the fire and by use of the damper. Opening the oven door will rapidly cool a hot oven. The oven temperature is influenced by other uses of the range. If much water is heated by the range for the hot water supply, or if the top flue above the oven is used as a hot plate, much heat will be taken away which would otherwise go to the oven.

An oven door with a glass window is convenient for observation of the temperature and the progress of baking. A mercury oven thermometer is more accurate than the usual metal thermometer attached to the oven door. These mercury thermometers are so made that they will stand in the oven and may easily be read through the glass window.

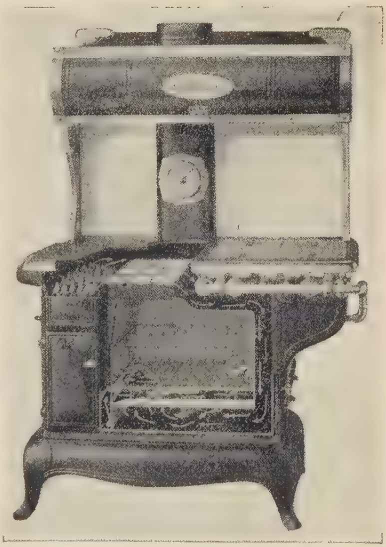


FIG. 72. — A combination coal and gas range.

91. The gas range. The gas range is not only a great convenience, but may be an economy if intelligently operated. Its cleanliness and readiness for instant use make a strong appeal, and in most

houses the gas range is the most important gas appliance. It is necessary to understand the proper use of gas and the care of gas appliances, in order to keep these appliances in good working condition and thus make the gas an efficient means of cooking.

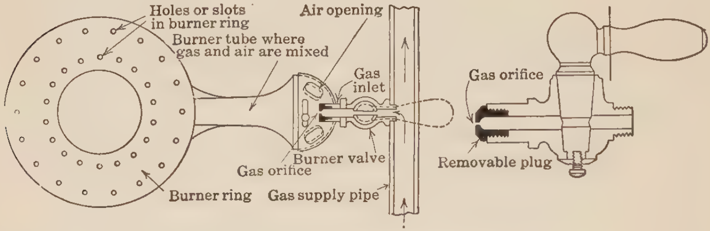


FIG. 73. — The gas burner.

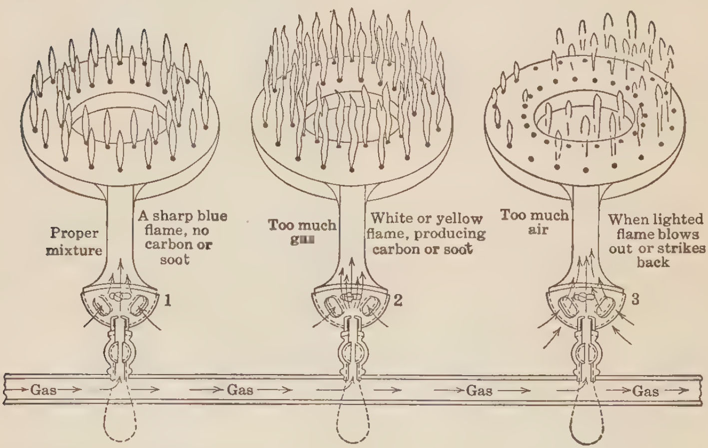
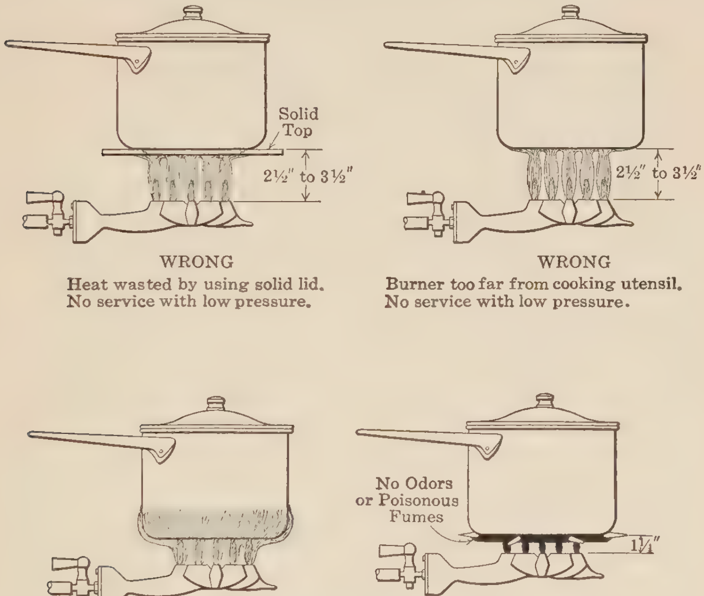


FIG. 74. — (1) Proper gas mixture. (2 and 3) Improper gas mixtures.

92. Top burners. The top burners, Fig. 73, are of the Bunsen type; that is, there is a burner tube at the base of which is a small orifice for the entrance of gas. Air enters the burner-tube openings in the shutter and mixes with the gas. The mixed gases pass through a small hole in the burner ring

and are burned. When the range is first installed, the air shutter on the mixing chamber is adjusted to admit the proper amount of air to give a sharp, blue flame. Not enough air should be admitted to allow a flame to strike back into the mixing chamber, even when the gas is turned low. If too



WRONG
Heat wasted by using solid lid.
No service with low pressure.

WRONG
Burner too far from cooking utensil.
No service with low pressure.

WRONG
Gas turned too high.
Odors, poisonous fumes, waste of gas.

CORRECT
Cooking utensil on grate, one and one quarter inch above burner, with flame just reaching bottom of utensil. — Good service with low pressure.

FIG. 75. — Right and wrong use of gas.

little air is admitted, the flame will be yellow and will produce soot. The burner may smoke if it is dirty, if the air mixer is clogged, or if the shutter is accidentally closed. If the burner becomes dirty and greasy, it should be boiled in water containing washing soda. All gummy material or dirt should be thoroughly removed. If the flow of gas is

weak, perhaps the orifice of the gas tube needs cleaning out. This may be done with a very fine needle or wire. Plugs with different-sized orifices can be used on some range burners, making it easy to select one to give the right amount of gas for the particular place or for a particular gas pressure. If the valve of the gas burner is tight, remove the screw underneath and take the valve out, clean it by rubbing with oil and powdered graphite, and replace.

93. The gas oven. The burners on the gas oven are also of the Bunsen type, and their adjustment is based on the same principle as that for the top burners. In lighting the oven burners, be sure to open the oven door before applying a flame to the gas, lest an explosive gas mixture in the oven cause damage. A small pilot light is usually provided, by means of which the oven burner is lighted when the burner valve is opened. The oven requires a large supply of gas. The products of combustion — water vapor and carbon dioxide — if allowed to escape into the room, are objectionable. Sweating of the walls and windows results and the oxygen value of the air is reduced. Some of these objectionable features are absent when a stovepipe is provided to carry the products of combustion to the chimney flue. It is well to have a damper in the stovepipe to regulate the draft when the burners are turned low, and to shut off the draft when the oven is not in use. It is desirable, also, to have a hood over the stove, with an opening to the flue at the top, to carry off the water vapor and odors which come from cooking food. The rusting of the oven indicates a faulty draft, which fails to carry off the water vapor. If the oven becomes rusty, the iron should be cleaned by rubbing with a stiff brush. It should then be warmed and tallow should be rubbed upon it.

The ordinary gas oven is very wasteful of heat. The walls give out about as much heat into the room as is used in the oven itself. Some ranges are now made with insulating material surrounding the oven, saving from 25 to 50

per cent in gas and in the time required to get the oven to the baking temperature.

94. The Loraine oven heat regulator. The oven heat regulator is a device which automatically regulates the oven temperature. The operation of this useful device will be understood by reference to the diagram, Fig. 76. The inlet tube *I* is connected to the gas supply pipe. The copper tube *E* is inside the oven at the top. When wheel *A* is turned in one direction, it pushes the spindle *B* to the right, causing pressure against the end of the lever *G*. The lever is pivoted at *C* on the end of a porcelain rod *F*. By this lever action the lower end is pushed to the left, compressing the spring *H* and opening the gas valve *K*, allowing the gas to pass through *J* to the oven burner. Gas enters through the tube *I*. After the oven gets warmer, the copper tube *E*, which holds the porcelain rod, expands much more than the porcelain. This allows the end of the porcelain rod *C* to move to the right. Since the porcelain rod is always kept close to the right end of the tube by the pressure of the spring *D*, when the end of the porcelain rod *F*

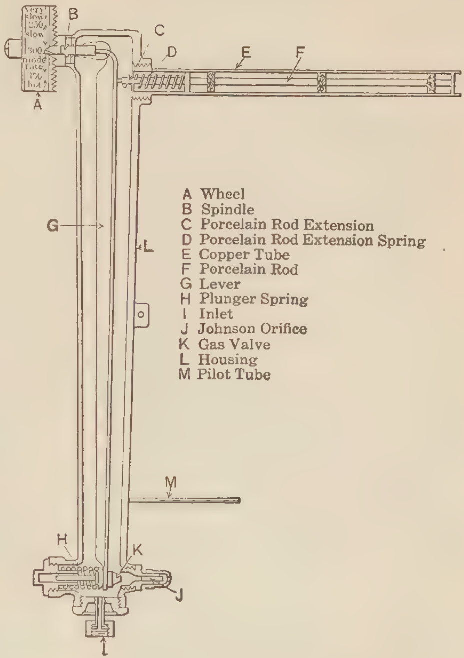
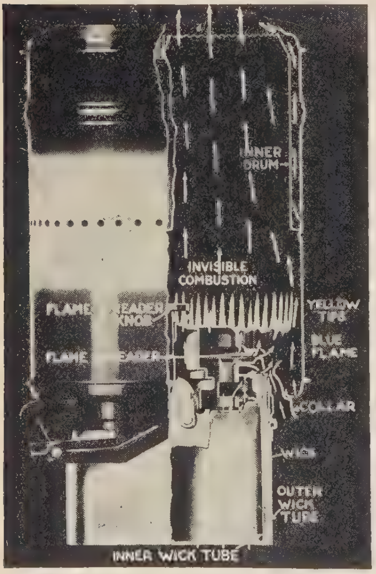


FIG. 76.—The Loraine oven heat regulator.

moves to the right, the spring H partly closes the inlet at J and reduces the flow of gas to the burner. After the oven cools a little, the action is reversed, as you will easily see by a little study. A pilot flame is always burning, so that if the gas is shut off completely, and then turned on, it will light automatically. This is more likely to occur with natural gas than with manufactured gas.

95. The kerosene range. The best types of kerosene ranges are those that give a blue flame. They are made with one or several burners. Each burner has a wick within a cylindrical holder, Fig. 77, which is merely a shell around an open center through which



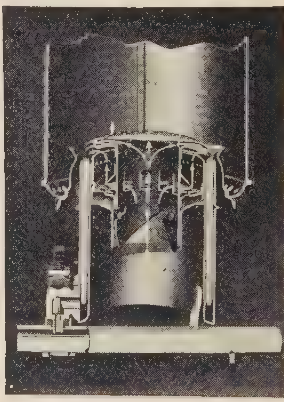


FIG. 77. — The kerosene range burner in action. Burner section with connection to oil pipe shown at right.

air rises. At the top of the central air space, a heavy metal cap with many perforations distributes air evenly. It also becomes heated and conducts heat to the metal wick-holder, and thus heats the kerosene, which is vaporized. The kerosene vapor, mixed with air, burns and gives a

flame of the same type as the Bunsen gas flame. It can be depended upon to give a clean flame, as there is no danger of smoking. The burner receives kerosene from a small pipe connected to a constant-level tank, supplied automatically from a reservoir, as in Fig. 78. The reservoir is like an inverted bottle with its mouth open under the liquid in the tank. When the kerosene level drops below the mouth of the reservoir, air enters the reservoir and permits kerosene to flow into the tank.

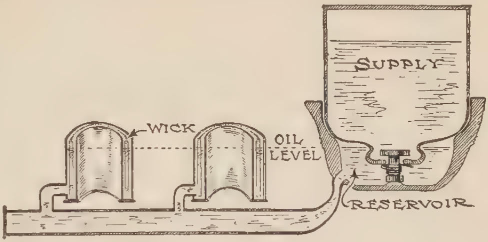


FIG. 78. — Section of kerosene range showing how oil is supplied to the wick.

96. Principle of the fireless cooker. Since the cooking of most foods consists merely in keeping them at a temperature of approximately 180° F. to 212° F. for a certain time, it is not necessary in such cases to have a fire during the entire cooking process. If a food, warmed to 212° over a fire, is removed from the fire, it will continue to cook until it has cooled 20 to 40 degrees.

A hot body cools because it loses heat to surrounding material. Air is a poor conductor of heat, but a hot body in air sets up convection currents which continually bring a fresh supply of cold air into contact with it. By surrounding a hot body with a good heat insulator, which does not permit convection currents, the time during which a high temperature can be maintained is lengthened. A fireless cooker is a device employing heat-insulating materials to prevent the loss of heat from the food and thus continue the cooking without the use of fire.

For many years the Norwegians have been accustomed to wrap a dish of hot food, taken from the fire, in a blanket

or to pack it in straw. In the early history of cooking, we are told that heated stones were dropped into water to heat it, or placed around food to cook it. The same principle is used to day in the most scientific method of cooking. Today, we heat stones and place them in heat-insulated chambers with the food that is to be cooked. We thus attain great efficiency of labor and fuel by conserving the heat.

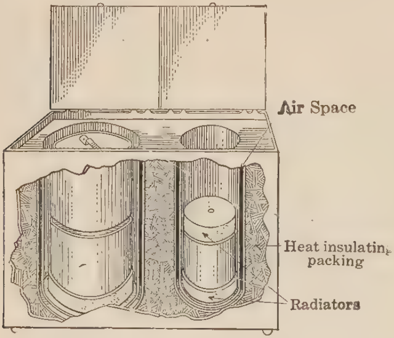


FIG. 79. — A fireless cooker.

79. The common fireless cooker and equipment. Most fireless cookers found on the market are lined with aluminum or zinc. The inside packing is asbestos, mineral wool, magnesia, or some other non-conducting material. Cooking utensils to fit the various compartments, racks for holding pies, and radiators form the equipment. The radiators are usually cast iron or soapstone. The soapstone is porous and breaks more easily than the iron, and the iron rusts badly. Both, however, when placed in the cooker, will maintain a higher cooking temperature than is possible without them. If above 250°, the lowest "sizzing" temperature, the radiators cause excessive evaporation of water when foods are cooked in water. The covers of the cooker compartments sometimes have valves which permit the escape of steam.

98. Advantages of the fireless cooker. In addition to the advantages of the fireless cooker arising from its maintenance of an even cooking temperature without watching, and a cool kitchen in hot weather, it effects a great saving of fuel. The usual processes of cooking are extremely wasteful because only a small part of the heat produced is utilized for

cooking. By use of the fireless cooker, fuel need be consumed only a short time to heat the food and the radiators to the cooking temperature; the insulating material of the cooker prevents the escape of heat and maintains this temperature.

99. Direct gas-heated fireless cookers. Gas ovens are now made with double walls containing an insulating material, such as asbestos, magnesia, or air. Food may be heated in this oven by the direct application of the gas flame. When the oven reaches the desired temperature, the gas may be entirely or nearly shut off. Because of the insulating wall, the food will cook as in the common fireless cooker with little or no further consumption of fuel.

100. Electric cookers. Because of the greater cost of electrical heat energy, good insulation is found in electric ovens more frequently than in gas ovens. The electric heat can be applied to better advantage within an insulated chamber, because there are no gases of combustion to remove. When the electric current has warmed the oven to the desired temperature, it can be turned off; or if the baking requires a long time, a small amount of current can be kept on continually to make up for the loss, thus maintaining a constant temperature at comparatively small cost.

SUMMARY

1. The coal range, by its construction, makes it possible to utilize the heat of burning fuel advantageously in cooking by boiling, steaming, broiling and baking.

2. The gas range has two sets of burners, both of the Bunsen type. These are: top burners over which are placed dishes containing foods to be cooked; and the oven burners for baking. It is desirable to have the products of combustion carried to the chimney in all cases, but it is much more important to do this with natural gas than when manufactured gas is used. Gas oven temperatures can be regu-

lated automatically by having certain attachments made to the range.

3. By a special type of burner, kerosene is vaporized. It gives a non-luminous flame which is used in the kerosene range for cooking, including baking.

4. Most of our cooking can be accomplished at a temperature between 180° and 212° F., though in baking and roasting the temperature may go as high as 500° for the surface layers of the food.

5. The fireless cooker is a device in which a hot food retains its temperature, through heat insulation, until it is cooked. The most common use of the fireless cooker is for foods that are usually cooked in boiling water, but it is successfully used in baking by adding heated radiators.

6. The fireless cooker saves fuel, makes it unnecessary to heat the kitchen in hot weather, and improves the texture and flavor of many cooked foods.

7. The fireless cooker principle of insulating walls is applied to gas-heated and electrically heated ovens, with a saving in the cost of heating.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. Development of cooking devices.
2. Relative merits of the steam cooker, pressure cooker and fireless cooker.
3. A study of flames.
4. Testing a fireless cooker: (1) as a cooker; (2) as a refrigerator substitute.

REFERENCE BOOKS

FREDERICK. *Household Engineering.* American School of Home Economics.

INTERNATIONAL LIBRARY OF TECHNOLOGY. *Hot Air Heating, Drying and Cooking by Steam.* International Text Book Company.

CHAPTER IX

SMALL HEATERS

101. Convenience of small heaters. There is scarcely a home that does not contain a portable heating device, using gas, gasoline, kerosene, or alcohol for fuel. Besides being used in summer for cooking and the laundry, these portable stoves are convenient in cold weather for warming the house. The oil and gas stoves will quickly warm the bathroom, or take the chill from the dining room in the morning. In early fall and late spring, the small heater gives all the heat desired. In severe winter weather, when the house heater is taxed to its utmost, these small heaters give useful auxiliary heat in the rooms where it is most needed. They may also be used to prevent pipes from freezing, or to save vegetables and fruits in the cold closet. The popularity of these stoves is due to their convenience and efficiency. Heat may be obtained at a moment's notice; the heat is applied where it is needed; and fuel is consumed only while it is producing useful energy.

FIG. 80. — An electric radiant heater.

102. The electric heater. When cleanliness, ease of operation, and hygienic results are the only things to be considered, the electric heater stands first. The electrical energy, in passing through a suitable resistance, is changed to heat, and also produces a pleasant, glowing light. The heating element radiates heat

in all directions. That which goes to the back is reflected so that it joins that radiated to the front, with the result that a strong radiant heat is given in front of the heater. In many localities the cost of electricity makes this heater too expensive for common use; but in others where electrical energy is cheap, or where a special low rate is given for heating purposes, the device holds well-deserved popularity.

103. The blue-flame gas burner. Almost all gas appliances in use today are of the *blue-flame* type. See pages 110 and 111. These burn gas on the "Bunsen principle." Burners of the Bunsen type have a mixing chamber with both gas and air inlets. By suitable regulating devices on the gas and air inlets, the proper amounts of air and gas for a good heating flame are brought together. Too much air will decrease the heat and may cause the flame to "strike back." Too much gas will produce a yellow and smoky flame.

104. Luminous-flame burners. In some heating devices no chamber is supplied for mixing the gas and air just previous to burning. All the oxygen for combustion must be supplied from air surrounding the gas. The flame is yellow because the carbon particles in the gas are heated to incandescence before they are finally burned. Great care must be used in regulating the height of the gas flame. If the flame is too high, the carbon will not be burned and a smoky flame will result.

105. The gas heater. Of the various gas heaters, those of the reflector type, Fig. 81, are perhaps the most efficient. These may have either the *luminous flame* or the *blue flame.* The flame of the reflector stove must not touch any part of the stove. The burner-tip orifice must be kept clean and open. If the stove is of the luminous-flame type, the gas flow must be regulated so that no smoke will result. The luminous flame, although 200° cooler than the blue flame, radiates more heat.

Heat from the gas flame is radiated to the corrugated copper or brass surface below the flame. This surface is kept bright in order to reflect the heat out into the room. The top of the stove becomes very hot and heats the air by convection currents. This is particularly true if the stove is connected to a flue, for then the gases from combustion pass directly under the top. When no flue connection is made, the products of combustion escape into the room. When natural gas is used, a flue connection should always

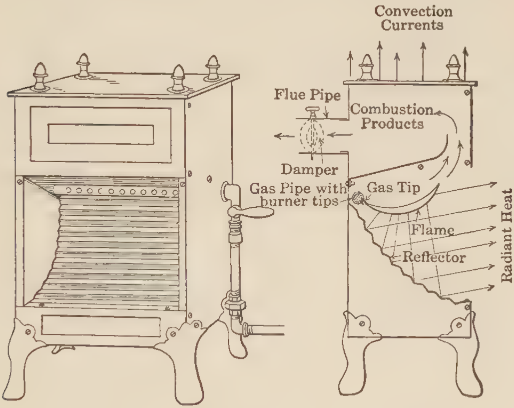


Fig. 81. — Reflector type of gas heater.

be made. When manufactured gas is used, a flue connection is desirable, but the danger without it is less than when natural gas is used.

106. Dangers from flueless gas heaters. When gas burns with an ample supply of oxygen, carbon dioxide and water vapor result. If these escape into the room, some discomfort, but no serious harm, is likely to result. With a limited supply of oxygen, incomplete combustion follows, and carbon monoxide is produced. Carbon monoxide is an odorless gas, so deadly poisonous that air containing one-tenth of 1 per cent will produce fatal results in a very

short time. Improperly adjusted gas heaters may give off carbon monoxide. Within a period of ten weeks in 1923, out of eighty-one cases of carbon monoxide asphyxiation in Ohio, thirty-four were fatal. This danger is not limited to Ohio, however, for there are in the United States over two thousand towns using natural gas and about five thousand towns using manufactured gas.

107. Moisture from burning gas. Another reason for removing the products of burning gas is to prevent condensation of moisture on the walls and windows. The amount of "sweating" produced in this way, of course, depends upon the quantity of gas burned. The moisture, when not removed through a flue, does damage not only to the woodwork and paper or paint on the wall but also to any iron materials, as flatirons, knives, tools and cooking utensils, through the rust that is caused. The quantity of water resulting from burning gas is indicated in Table XII.

TABLE XII

THE COMBUSTION OF GAS

	Requires	Yields	
		Carbon Dioxide	Steam
1 cubic foot natural gas	10 cubic feet of air	1 cubic foot	2 cubic feet
1 cubic foot manufactured gas	5 cubic feet of air	$\frac{1}{2}$ cubic foot	1 cubic foot

The water which comes from the condensation of steam resulting from the combustion of 1000 cubic feet of natural gas has been calculated to be about $10\frac{1}{2}$ gallons, and from 1000 cubic feet of manufactured gas about 5 gallons. One pint of water in the form of vapor will saturate 5300 cubic feet of air. Suppose a natural gas heater consumes 125

cubic feet of gas a day; that quantity of gas will yield $10\frac{1}{2}$ pints of water vapor, or enough to saturate 55,000 cubic feet of dry air. But air is seldom dry. If this air were half saturated at the start, the added moisture would be enough to saturate 111,000 cubic feet, and with less air present some of the moisture would be deposited.

108. Connection of gas stoves. Unless a person is in constant attendance where a gas stove or a gas lamp is burning, it is not safe to use rubber or flexible tube connections. The splitting of the ends where connected to the gas pipe or to the stove, and the resulting escape of gas, has been followed by serious consequences. A metal pipe connection with tight joints is the *only safe way*.

109. The gas iron. Many housekeepers find the gas iron a convenience and an economy. It is a hollow iron with holes on the sides for air to enter and for the escape of the gases of combustion. It is fitted with a burner of the Bunsen type, and connected to the gas jet by a flexible tube. Gas irons require attention and care to keep the air-and-gas mixture properly regulated.

Fig. 82. — Kerosene heater.

110. The kerosene heater. The central-draft, wick heater is one of the popular types of kerosene heaters. This gives a cheery, luminous flame which can be seen through the gauze or mica window, and is exceedingly efficient in warming a small room. Water can be boiled in a dish set on top of the stove. A damper closes the holes in the top surface when the stove is used to warm the room, but this should be open if it is used to warm anything placed upon it.

The burner is hollow and adapted to the use of a cylindrical

wick. The wick can be raised or lowered by turning an adjusting wheel, which turns cog-wheels engaging holes in the metal wick carrier. Covering the central opening of the burner is a flame spreader, one shoulder of which just covers the top of the wick. When the wick is turned low, it is completely covered with the metal and no air has access to it. In the vertical wall above the shoulder are many small holes through which air comes to supply oxygen to the inside of the flame. The flame spreader must be kept thoroughly cleaned; the carbon must be kept from the metal which covers the wick; the air holes must be kept open by the occasional use of a stiff brush. The wick tubes need cleaning with fine sandpaper. If the holes in the flame spreader or in the base outside the wick tube are allowed to clog, insufficient air will be secured, and smoking will result. Loose threads from the poorly trimmed wick will sometimes cause smoking. If kept in proper condition, an oil heater should not produce the disagreeable odors which are common with neglected oil heaters.

Watch the oil dial and never allow the reservoir to go dry, because burning of the wick will follow. Under proper use, about one-quarter of an inch of the wick is exposed. From this the oil vaporizes, and is burned. There should be little or no burning of the wick itself.

111. The flat-wick kerosene stove. Small kerosene stoves for cooking purposes are extensively used. These are made with one, two, three and more wick units. They burn with a luminous flame, give strong heat, and are efficient stoves. It is not safe to light one of these stoves and leave it alone, because as the stove gets heated, the kerosene is vaporized more easily. Frequently, the vaporization is so profuse that the oxygen cannot be applied in sufficient quantity; when this occurs a dense cloud of carbon will cover the dish on the stove, and the air of the room will become filled with dense flakes of soot. Never turn the wick as high as it will stand at the start, and unless you have

had experience with such a heater, do not go away and leave it burning.

112. Alcohol stoves. Alcohol, as a source of heat for the chafing dish, has a strong rival in electricity, which is efficient and without fire danger. The chafing dish font for holding the alcohol is usually filled with absorbent asbestos fibers, held in place by the wire gauze. The font is filled until the absorbent material is saturated with alcohol. It is then lighted. The fibers act as a wick (capillary action) in bringing the alcohol to the surface, where it is vaporized and burned. A metal cover can be placed over the burning flame at any time to extinguish it. A convenient alcohol fuel is " solidified alcohol." This is a preparation having a paraffin base holding in a solid state a considerable quantity of alcohol. A wickless alcohol stove has an elevated reservoir to hold the alcohol which is fed slowly through the pipe to the burner.

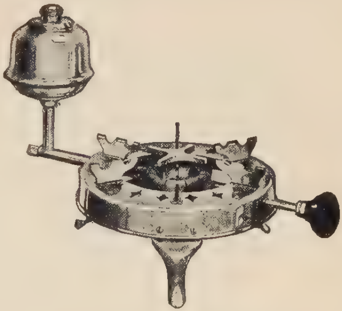


Fig. 83. — An alcohol stove with elevated reservoir.

113. The blast torch. A blast lamp using kerosene, alcohol, or gasoline is frequently found in the home. It is particularly useful in soldering and in many other ways, for the man who is mechanically inclined. All these lamps operate on the principle of the plumber's torch. Air is pumped into the reservoir, from which the liquid fuel is forced by this air pressure. The outlet is through a very small jet at the end of a metal tube. The metal tube is so placed that, when the flame is started, the tube will be kept hot and the fuel inside vaporized, so that only a gas issues from the jet outlet. To start the torch, fuel must be burned in a small cup under this tube to heat it sufficiently to vaporize the liquid.

114. The gasoline camp stove. For the camping auto tourist, a gasoline stove is ready for almost instant service. This stove may have one or several burners, shielded from the wind for out-of-door use. At one end of the stove is the gasoline reservoir with a small air pump attached. The gasoline is delivered under pressure to the burners, where

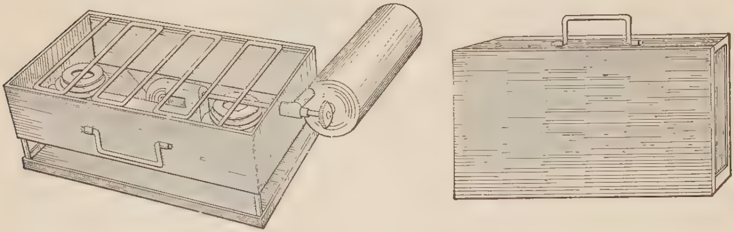


FIG. 84. — A gasoline stove for camping use.

it is vaporized. The principle of operation is the same as that of the blast torch, but the burners are of different form so that vessels for cooking may be set upon grates over the fire. In all burners of this type the liquid or the vapor fuel is delivered through a very fine orifice, which must be kept free from obstruction. It is, therefore, necessary to have perfectly clean fuel put into the reservoir. If the orifice becomes clogged with dust, fine sand or other matter, it is usually possible to clear the opening with a fine wire or priming pin.

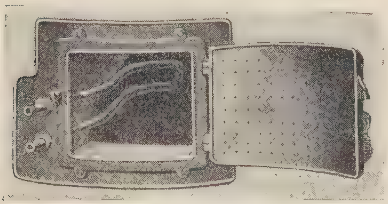


FIG. 85. — Furnace attachment for hot-water supply.

115. Hot-water supply. A convenience which has become almost a household necessity is that of a constant supply of hot water to various parts of the building. A supply of hot water in sufficient quantity for household purposes, and ready for instant use upon opening the faucet,

is easily secured. The most common way to heat this water is in a water pipe which is placed inside the lining of the fire-box of the coal range. It is sometimes heated by a coil of pipe which passes into the furnace. For summer, and for houses which use no coal stove in the kitchen, the gas heater serves well. For country houses where no gas is available, a similar plan, using kerosene instead of gas, gives satisfaction. A large galvanized-iron or copper storage tank is needed to hold enough water for the regular washing, for the bath, and other household purposes.

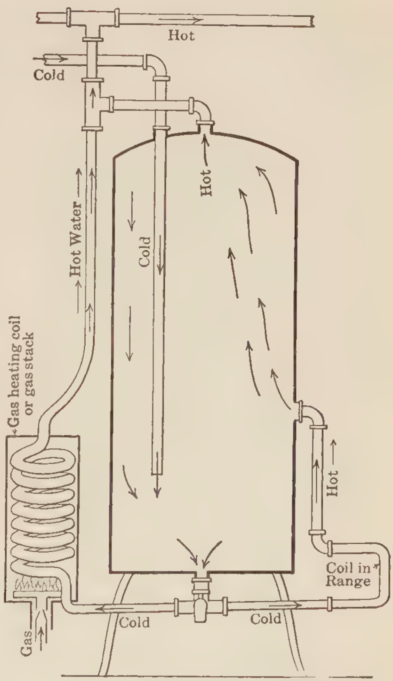


Fig. 86. — Hot-water supply tank, with range and gas coil connection.

116. Hot-water system explained. A pipe leading from the bottom of the tank connects with the water front of the coal range. After making a circuit in this, it goes back to the tank, passing through the side of the tank about halfway to the top. If a gas heater is used, the hot water goes from the heater directly to the discharge pipe at the top of the tank, because, when gas is used, we frequently want a small amount of hot water, but we want it at once. By this plan hot water is delivered to the faucet without passing through the tank. If, however, the pipe entered the tank as does that from the stove, the hot water would mix with the cold water in

the tank and we could get no hot water until a large amount of water was heated, thus causing considerable delay.

When hot water is drawn from a faucet, a supply of cold water enters from the supply pipe, which passes through the top of the tank and extends down to a level just above the top of the heating device. It is unsafe to have the supply pipe extend lower than this, else the water would be drained from the heating coil or water front in the range. If these pipes were drained without extinguishing the fire, the pipes might get red hot and then, if water were admitted, the sudden production of steam would result in a serious explosion. Sometimes a tank, usually placed in the attic, supplies water directly to the hot-water tank. This supply, or expansion tank, receives water from the supply pipe and is automatically regulated by a floating ball-valve control.

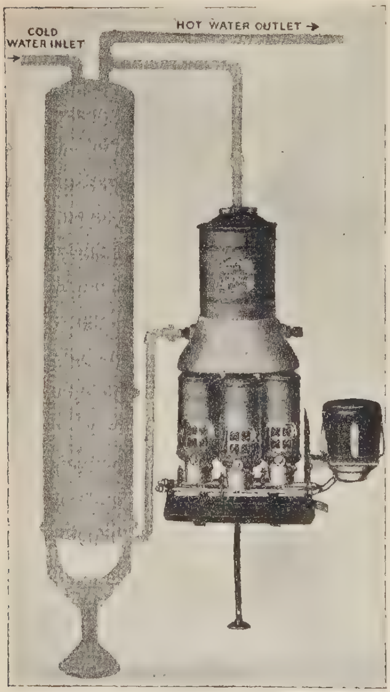


Fig. 87.— Hot-water supply with kerosene as the source of heat.

PROBLEMS

1. Apply the principle of convection, and explain the movement of water in the system when the fire is warming the water in the water front of the stove and the faucets are all closed.

2. Explain the movement of water in the system when the hot-water faucet is opened.

117. Combination of heating sources. It is a good plan to have the hot-water tank connected both to the coal range and to a gas or kerosene heating device; either one may then be used independently of the other, or both at the same time. If a coal range is not used, the furnace may be used to heat the water in the winter.

118. Care of the hot-water system. Water should be drawn from the faucet under the tank, from time to time, to remove the sediment. The water front must never be drained when there is a fire in the stove, else it may crack or perhaps cause an explosion. Coils of pipe running through the stove or furnace need attention occasionally if the water is hard. Deposits of calcium carbonate make heating slower and may even cause stoppage. If water gets boiling hot, and bubbling or rumbling is heard, open a hot-water faucet; this lets cold water in and prevents the generation of steam, which otherwise might produce enough pressure to strain the joints. It also might force the water from the water front and allow it to become overheated; then when the pressure was relieved and water entered the overheated water front, the sudden formation of steam might result in an explosion.

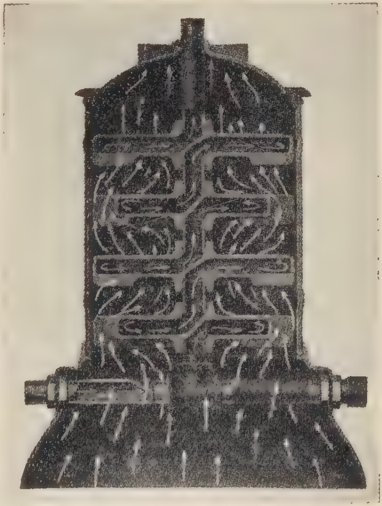


Fig. 88. — Section of kerosene heater used for hot-water supply.

119. Automatic and instantaneous gas water-heaters. Some heating devices are so arranged that, when the water

is turned on, it automatically turns on the gas to warm the water, and when it is turned off, the gas is turned off too. A small pilot light, which is burning all the time, serves to light the gas when it is turned on. There is a very long coiled pipe through which the water flows; in this, the water

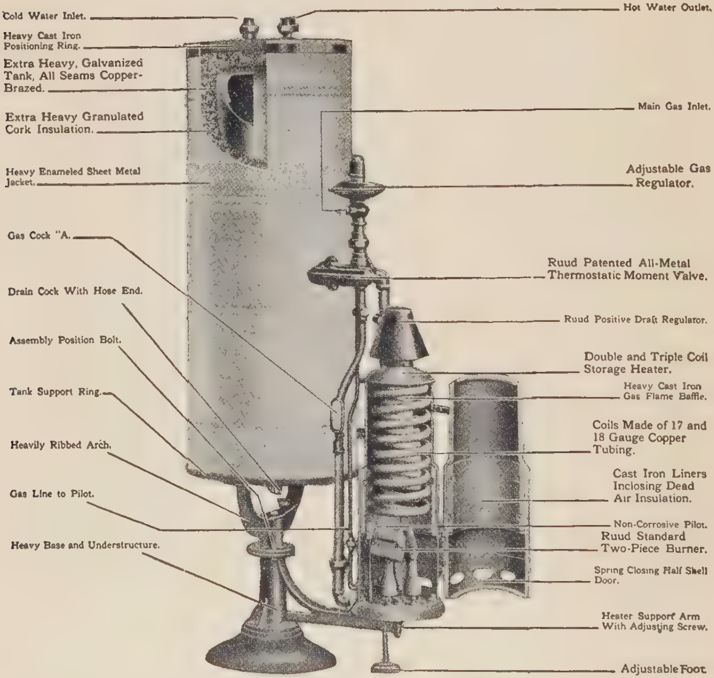


FIG. 89. — A well insulated storage tank used in the automatic hot water supply.

is heated hot as fast as it passes through. With such a heater no tank is needed. The gas may burn low all the time, keeping the water warm, but raising the temperature of that which flows away when the faucet is open. It is generally advantageous, especially for a rapid flow of water, to

have a supply tank used with an automatic heater, as is shown in Fig. 89.

120. Freezing of hot-water pipes. It is a very common occurrence for hot-water pipes to burst in cold weather when cold-water pipes are unharmed. This is not due to any difference in the freezing temperatures of the two, but rather to several other reasons. The cold water has not been heated and so contains air dissolved in it. Upon

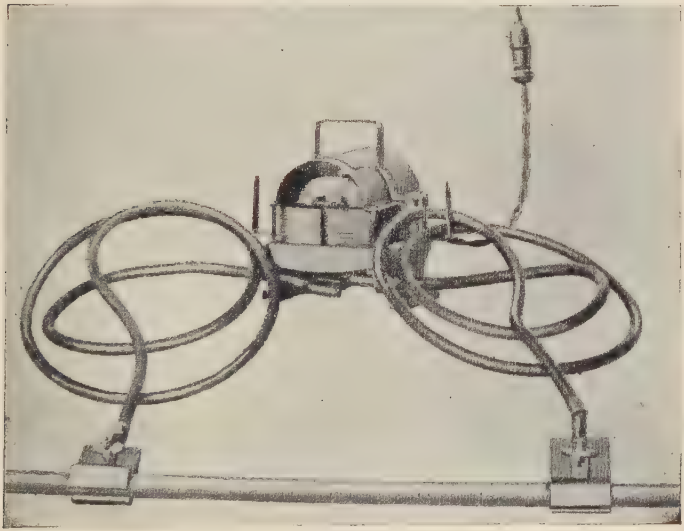


FIG. 90. — Device for thawing frozen water pipes by means of electricity

freezing, the air separates and, because it can be compressed, serves as a cushion to take up the expansive force of the freezing water. On the other hand, water that has been heated has lost its dissolved air, and so the full force of the expansion due to the formation of ice is directed against the pipes. Hot-water pipes are commonly made of brass, while cold-water pipes are of iron. Brass is a better conductor of heat than iron and so cools faster. Iron is stronger than

brass and consequently resists pressure of expanding ice with more force than brass does.

When water begins to freeze in the pipe, its pressure in the enclosed space is increased. An increase in pressure lowers the freezing temperature; therefore water will not burst a pipe unless its temperature is considerably below 32° F. Thawing frozen water pipes with lamps, torches or any bare flame is a serious fire hazard. Frequently a pipe can be cleared by the use of boiling water or hot cloths. By means of an electric thawing device, Fig. 90, the pipe can be thawed quickly and without danger from fire. The device is a step-down transformer (see page 209) which lowers the voltage taken from the lighting circuit but steps-up the heat-producing current. It consumes about the same amount of electrical energy as an electric iron. A faucet is opened and the clamps from the secondary coil are placed on the pipe a short distance apart. The pipe is heated in sections until the water runs, which usually occurs in a very short time.

SUMMARY

1. Small heaters give an important service in the home; in cool weather and on cold mornings they remove the chill from the room, and in severe cold weather they are used for auxiliary heat to help the larger heaters.

2. Disregarding the possible expense of operation, the electric heater offers more advantages than any other small heating device.

3. Gas heaters of both the blue-flame type and the luminous-flame type give satisfactory service. With any gas heater care must be taken to see that the combustion is complete, else the deadly poisonous carbon monoxide will be set free. It is better to carry the products of burning out of the room by means of a flue connection.

4. A large amount of water vapor results from burning gas. If there is no flue connection, this will condense on

windows, walls, and various objects in the room, often doing much damage.

5. One of the most popular small heaters is that which burns kerosene. It has a central draft and works like a huge central-draft lamp. When kept clean and trimmed, this stove is economical and gives excellent service.

6. For some purposes, as in the chafing dish and other small cookers, alcohol is often used. The alcohol flame never smokes or blackens the dishes placed over it. It burns freely and gives a hot flame.

7. There are many devices of the blast-torch type, burning kerosene, gasoline, or alcohol. They all have a fuel reservoir into which air may be pumped to give pressure for forcing the liquid fuel out. The fuel is vaporized so that a gas flame is produced. The gasoline camp cooker is one of this type.

8. In one type of hot-water supply, a storage tank is used. This is connected by pipes to a heating coil situated in the range or furnace, or in a separate unit for gas or kerosene heating. The heating coil should never be drained unless the fire is extinguished, for if it is, the coil will get so hot that, when water comes into it again, steam may be generated under sufficient pressure to cause an explosion.

9. Automatic, instantaneous water heaters do not require a storage tank. Opening the faucet automatically turns on the gas flame, and closing the faucet shuts off the gas. The water is heated hot as it flows through the pipe in the heater.

10. In cold weather the hot-water pipes are more often frozen than the cold-water pipes because, in freezing, the cold water liberates air which serves as a compressible cushion. Brass pipes cool more quickly and are less strong than iron pipes.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. Small heaters as fire hazards.
2. Merits of different types of heaters for hot-water supply.
3. Compare the humidity of the air in a room, before and after using a small heater for two hours.
4. Compare the relative costs and efficiencies of a kerosene and a gas stove.

REFERENCE BOOKS

Frederick. *Household Engineering.* American School of Home Economics.

Safeguarding the Home Against Fires. National Board of Fire Underwriters.

Safety for the Household. Circular 75. United States Bureau of Standards.

CHAPTER X

HOUSE HEATING: THE STOVE AND FURNACE

121. Heat exchange between a person and objects in the room. We have already referred, in Chapter V, to the exchange of heat between bodies of different temperatures and to the resulting loss of heat by the warmer body. Let us now consider the application of this principle to a person entering a room with furnishings. If the room is unheated and a person enters it on a cold winter day, he soon feels cold. The air and objects in the room are very much colder than the person. Whenever two bodies are touching or are near each other, there is an interchange of heat energy, the warmer always losing to the colder. Heat from the person's body passes through his clothing by conduction and air movement. Heat is also radiated to the walls and to objects in the room. The walls and objects, being at a lower temperature, cannot radiate as much heat to the person as they receive from him. Hence the objects are warmed slightly, while the person cools off. The warmer the room the greater the amount of heat radiated to the person, and the less taken from him. Since a person is generating heat all the time, he should lose more than he receives. The proper balance is obtained at about 68° F. to 72° F. for an inactive person, but at a lower temperature for one doing vigorous, muscular work. An elderly person requires a higher room temperature than a younger person.

122. Minor sources of heat. In addition to the heat persons give to a room from their bodies, direct sunlight is an agent of considerable importance. It helps warm our houses in winter, if we let it in, and it gives too much heat in summer unless we shut it out. Not only does the light change to

heat when it is absorbed by matter in our rooms, but with the rays of light there are mixed the rays of heat, which have their origin in the sun. Proper arrangement of the shutters will make a marked difference in the comfort of rooms on the sunny side of the house.

Only those forms of artificial light which result from combustion are of importance in warming a room. The incandescent electric light gives out some heat, but the quantity is very small; especially is this true of tungsten lamps. Oil lamps and gas burners are the principal sources of heat from illuminants, though candles, when used freely, give considerable heat. The Welsbach burner, because of the small gas consumption per candle power, heats a room only one-tenth as much as the common fish-tail burner. Gas and oil lamps give off heat approximately as follows:

Oil lamp	160 B.t.u. per candle power per hour
Gas — Fish-tail burner	300 B.t.u. per candle power per hour
Gas — Argand burner	200 B.t.u. per candle power per hour
Gas — Welsbach burner	30 B.t.u. per candle power per hour

123. What it means to heat a room. One B.t.u. will warm 1 cubic foot of air 55° F. One pound of coal yields 12,000 B.t.u. It seems, at first thought, that a house might be warmed by burning a few pounds of coal. The problem of heating is not quite so simple, however. Much heat is lost through the chimney. Moreover, it is not merely the air which must be heated, but the floor, walls, woodwork and furnishings. The air of the room takes but a minute portion of the heat required. The amount of heat absorbed by the various materials in the room, in being warmed, depends upon their specific heat. Brick and air take about the same amount of heat, weight for weight, but pine wood will absorb twice as much heat as either brick or air in being warmed through the same change in temperature. It takes 20 per cent more heat to warm oak wood than it does to warm pine. Metals take less heat than wood or stone. Many times,

when a room is being warmed, the thermometer surrounded by air and protected from loss by radiation will record 70°, but we feel chilly. The walls of the room are not yet warmed to 70°, and we radiate an excessive amount of heat to them.

124. How a room loses heat. Heat is lost from a room in a variety of ways. There is some conduction and radiation of heat through the glass of windows. There is some conduction through the walls. Much leakage of warm air takes place through cracks around doors and windows or up the flue, if such a ventilation device is provided. It is possible that air may circulate to some extent through plaster and brick walls. How porous a brick is may be determined by weighing it dry and then reweighing after it has been soaked in water for several hours. The increase in weight represents the weight of water in the pores of the brick. Air may easily be forced through a brick and even illuminating gas will penetrate some bricks as shown in Fig. 91.

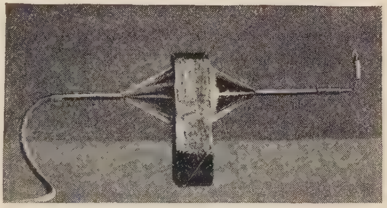


FIG. 91. — Some bricks are so porous that enough gas will pass through them to burn.

125. The house-heating load. The fuel needs for house heating are determined by the temperature of the atmosphere. As long as the minimum temperature during the day does not fall below 60° F., no artificial heat for warming the house is required; but when it does go below 60° F., heat must be supplied in order to make the house comfortably warm. The wide variations in daily and seasonal temperatures produce corresponding variations in heating needs. A study of a typical minimum temperature record for a year, Fig. 92, discloses the fluctuating demand made upon our heating systems. If the minimum temperature curve be inverted, all the space below the curve down to the 60° line

represents the "house-heating load." The greatest range results during the lowest temperature and this may be called the "peak load." The house-heating equipment must be of a capacity to take care of the peak load, though you will

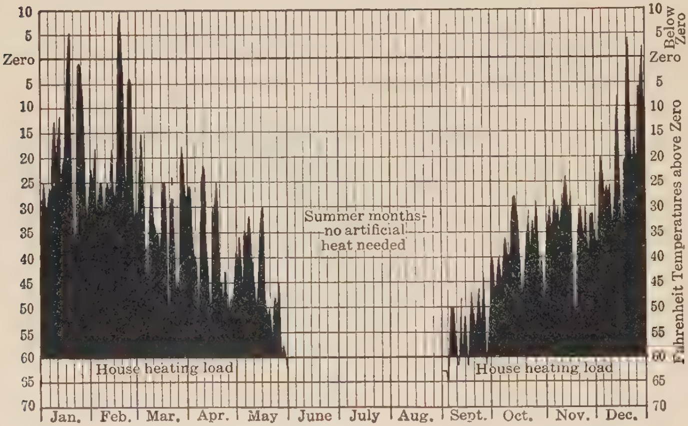


FIG. 92. — The house-heating load.

readily see from the chart that it will not be used to its full capacity very much of the time.

126. Modern fireplaces. The fireplaces in our modern houses are seldom built with the idea that they will give ample heat to the room, but rather that they may be used for auxiliary heating in extremely cold weather, or as the only source of heat in mild weather. Quite as often, however, the fireplace is used for the cheerfulness and coziness which it always spreads among any group gathered about it. The air in the room is not warmed much by a fire in a fireplace, but objects, walls, etc. are warmed by radiation. Since the air is not overheated, as it often is in other systems of heating, it retains more nearly its out-of-door humidity. This gives us a more agreeable feeling. Another advantage of the fireplace is that foul air is carried up the chimney. In

fact, a large amount of air not needed in combustion of the fuel passes up the chimney. This means a large loss in heat. The fireplace is not an economical heating device; only about 10 per cent to 20 per cent of the heat of the fuel is effective in warming the room in the best fireplaces. This, and the fact that the room cannot be heated uniformly, are the chief reasons why fireplaces are not used for practical heating.

127. Stoves. Stoves are used in the house for two purposes: heating and cooking. The construction of the stove depends upon its use and also upon the kind of fuel which is to be burned in it. There are certain essential features, however, which are common to all stoves. The ordinary kitchen coal range was shown on page 108. A coal stove for heating purposes is shown in Fig. 93. Coal is burned on a *grate*, below which is the *ash pit*. In the door of the ash pit is a slide, covering or opening holes in the door. This is the *draft*. The stove is joined to the chimney by a stovepipe, in which is a *damper*. When either the damper or draft is closed, the circulation of air through the fuel is reduced and the fire is checked. A *check draft* is placed in the door through which the fuel enters the fire chamber, and a second check draft is frequently placed in the stovepipe. Any air allowed to enter the stovepipe or the fire chamber *above the fuel* checks burning, as it reduces the air which passes *through the fuel*.

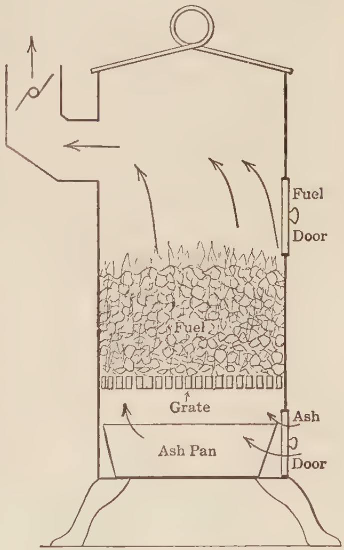


FIG. 93. — A stove.

The damper and draft are both open, and the check drafts closed, to secure the hottest fire. For some time after fresh coal is put on, there may not be enough air supplied for complete combustion. Carbon monoxide, a poisonous gas, will then result. The damper should, therefore, always be left open for a time after adding fresh coal, to allow the carbon monoxide to pass off.

128. The wood stove. The wood stove for heating use does not have a grate and an ash compartment below it. There is a draft and slide to the ash pit which is merely a basin-like depression at the base of the stove. The fuel chamber is larger than in the coal stove, because wood is more bulky than coal for the heat it can give. The burning wood rests on the hot ashes, and the air enters the draft. There is but one place for admission of air for burning. The stovepipe has a damper. Combustion is regulated by the proper manipulation of these two devices.

129. How a room is warmed. Our modern stoves are far more efficient than fireplaces, as they make use of 70 per cent to 80 per cent of the heat of the fuel. Air in contact with the hot surface becomes heated, expands, loses in density and is pushed up by denser air which comes in to replace it. The air in these warm currents is cooled by windows, the cold walls, and colder air with which it mixes, and at length it sinks to the floor, moves along the floor to the stove and finally pushes the warmer air upward, thus completing the convection circuit. Radiation also plays an important part in warming a room. The air absorbs but little of the radiated heat, but the furniture and walls receive much of their heat from this source.

The amount of heat a body receives by radiation depends upon its nearness to the stove, for the intensity of radiation varies inversely as the square of the distance. To illustrate, suppose a surface of 1 square foot is 2 feet away from the stove and it is then moved to a position 4 feet away from the stove. The distance has been doubled and the radiant heat

received will be but $\frac{1}{2 \times 2}$ or $\frac{1}{4}$ as much as when it was 2 feet distant. Multiply the distance by 3 and the heat will be only $\frac{1}{9}$ as great. What would be the heat received if the distance were made 4 times as great?

Cast-iron stoves with rough surfaces radiate more heat than smooth, sheet-iron stoves. Heat is brought through the metal, from the inside to the outside surface, by conduction.

130. The warm-air furnace. The warm-air furnace is in reality a large heater much like a stove, surrounded by a

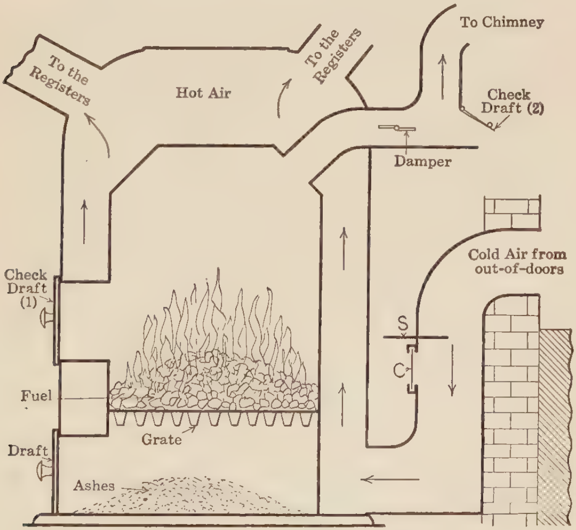


FIG. 94. — A warm-air furnace.

metal covering from which ducts lead to the rooms to be heated. In order to establish natural convection currents, the furnace must be lower than the rooms, and consequently we find the furnace, as a rule, in the cellar. The surface of the combustion chamber must be large, to warm the large volume of air which passes between the walls of the heater

and the outside covering, on its way through the ducts to the rooms. The operation of the furnace is practically the same as that of the stove. A check draft is commonly combined with the damper in the smokepipe. This is so arranged that when the damper is closed the draft is opened, thus admitting air from the cellar to the smokepipe without its passing through the combustion chamber. The other fire and air controls will readily be understood by a study of Fig. 94.

131. Source of the air supply. It is important that the air heated and sent to the rooms be pure. Out-of-door air is best. A cold-air flue is built to conduct this air from a cellar window to the furnace. The window which supplies this air should be on the windward side of the house, but where no pollution of the air is likely to take place. Preferably, this air inlet should be several feet above the ground and protected from rain, snow and dust. It should be well screened; a coarse cloth may be used in addition, to filter the air.

132. Regulation of the air supply. When the air is heated it expands. This increase in volume varies with the temperature. Four cubic feet of air from out-of-doors in extremely cold weather will give just as large a volume of air in the rooms as 5 cubic feet in mild weather. Hence, less cold air should be admitted in very cold weather. In the cold air flue there is a slide to regulate the volume of air which enters from out-of-doors. During very cold weather, out-of-door air has a high density, and so naturally the air in the convection currents moves faster than at other times. If too much cold air is admitted to the furnace, it is not warmed sufficiently unless the fire is increased. Much coal is wasted by neglecting the regulation of the cold-air flue.

133. "Burned" air. Care must be taken in the regulation of the air admitted, for another reason. If too little air is admitted, so that the air is not moved quickly out of the heating chamber, it will become overheated and result

in air which is very uncomfortable because of its "burned" condition. It often happens that air is passed over metal surfaces which are 1200° F. in temperature. Air which has been "burned" in this way is devitalized and lacks its usual health-giving properties.

134. Reheating the air. When few people are using the rooms, it is not necessary to draw an entirely new supply of air from out-of-doors. The cool air from the rooms or possibly from the cellar may be used. If the heating system provides for reheating the air from the rooms, the cold-

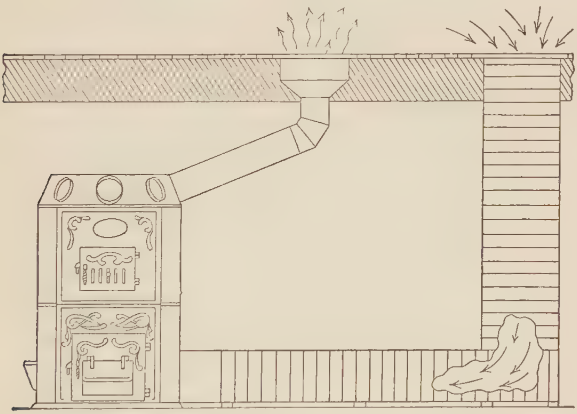


FIG. 95. — Recirculated air system.

air ducts should be placed near windows and near the bottom of a flight of stairs, if there be an open stairway with upper and lower halls. If this is done, the cold air which comes in around the windows and the cold air which comes down a stairway will be taken directly to the furnace to be warmed.

If air is to be taken at times from the cellar, a door is placed in the cold-air flue. When cellar air is to be used, this door is opened and the slide regulating the out-of-door air is closed. Many people close this slide at night and use

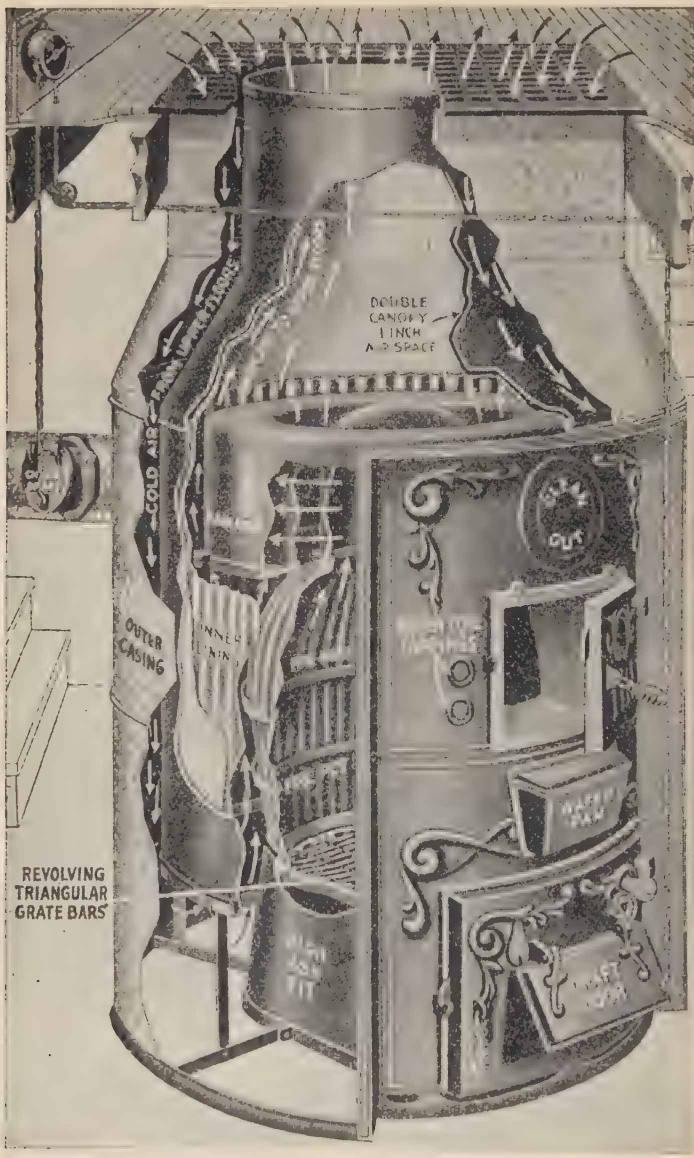


FIG. 96. — The one-pipe warm-air furnace.

out-of-door air only in the daytime. It is well to filter the cellar air, when used, by having it pass through cheese cloth as it enters the cold-air flue.

135. One-pipe and three-pipe furnaces. The *one-pipe* or *pipeless furnace*, Fig. 96, is a warm-air recirculation type of heater. It delivers warm air through one large register so placed that it will easily warm the principal rooms of the house. Other rooms opening off these will be warmed by the circulating air currents. Upstairs rooms may be warmed by having registers which allow warm air from the rooms below to rise into the rooms, or by convection currents by way of an open stairway. Cold air is returned to the furnace through a register which surrounds the warm-air register. Outside of the heater is the chamber for warming the air, and outside of this air-warming chamber is another chamber through which the downward currents of cold air flow. Little heat is lost to the cellar, because the cold air absorbs practically all the heat which is carried to the outside wall of the heating chamber.

The heating of distant rooms will be improved by having return ducts to bring cold air from them direct to the furnace. A furnace having two return cold-air ducts and one central warm-air duct is called a *three-pipe furnace*. It is like the one-pipe furnace in all respects except the manner of returning the cold air.

136. Advantages of the furnace. A furnace demands much less time and attention than the number of stoves it replaces, and it brings less dirt into the house than stoves do. Its efficiency may be only 50 per cent to 60 per cent, if all the air heated is drawn from out-of-doors; but if the cool air of the rooms is drawn back to the furnace and reheated, its efficiency may reach 70 per cent or 75 per cent, which is almost as high as that of our best stoves. The furnace is less expensive to install than either steam or hot-water heating systems. It gives heat very quickly after opening, and it may be altered easily and quickly. An unskilled

person can operate a furnace more easily than he can the steam or hot-water systems.

137. Disadvantages of the furnace. While the furnace is very satisfactory in small residences, in a very large building circulation of the air cannot be secured in all of the rooms unless there is *forced circulation* by fans. The circulation by *natural draft* depends upon the difference in weight of the column of air *inside* the duct and that *outside* the duct. Since this difference is very small, the force which causes the movement of air is also very small. In fact, there are two forces which frequently prevent certain rooms from receiving any heat at all. During a strong wind, it may be impossible to heat rooms on the windward side of the house, because friction opposes the movement of air through the ducts. This is most disastrous in long ducts which are nearly horizontal. It is with great difficulty that the warm air is carried through these pipes. It is sometimes advisable to install a small electric fan in the air ducts to push the air along. This insures movement of the air and is inexpensive to run. After the furnace is a few years old it may leak dust from the ashes and gases from the combustion chamber. These are carried to the rooms, where their presence is objectionable. Dust, which settles in the registers when not in use, is blown back into the room when they are used. The humidity of furnace-heated air is far below that required for good health and comfort.

138. A furnace humidifier. The water tank, usually set into the base of the air chamber of the warm-air furnace, is practically useless. The water in this tank does not get hot enough to vaporize quickly; and even if the tank is kept filled with water, which is rarely done, it cannot give an adequate supply of vapor to raise the humidity to the proper degree. An improved form of humidifier has an evaporator placed at the top of the heater, with an outside automatic water control. This consists of a small tank connected to the water-supply pipe. The entrance of water

is controlled by a valve operated by a ball float. The level of water in this tank maintains the same water level in the evaporator in the furnace.

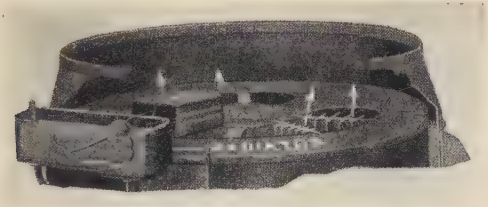


FIG. 97. — A constant supply of water to humidify the air as it leaves the furnace can be secured by means of this humidifier.

SUMMARY

1. When a cold room is heated, it is not the air alone, but also the walls and the objects in the room, that absorb the heat.

2. A room loses heat by leakage of warm air, by conduction through walls, and by radiation through windows.

3. Fireplaces give us pleasure and comfort but are extravagant users of fuel.

4. Coal stoves and furnaces have a draft to admit air beneath the coal, a check draft above the level of the coal in the fire chamber, a damper and a check draft in the smokepipe. By proper adjustment of these the fire is controlled.

5. The furnace warms the rooms by convection currents. Stoves warm them by convection and radiation.

6. The warm-air furnace does the work of several stoves. From some central location in the cellar, it sends warm air through metal ducts to the different rooms to be heated, through the use of convection.

7. It is important to regulate the air which is to be heated in the warm-air furnace. If too much is admitted it will be too cold; if too little, it will be "burned." Air may be

returned from the rooms for reheating, but in general it is better to take fresh out-of-door air.

8. The warm-air furnace is more convenient than stoves, but not quite as efficient. It gives satisfaction in small houses. Friction in the ducts prevents warm air from flowing to rooms which are distant but not much higher than the furnace.

9. The humidity may be increased by evaporating water at the top of the heater. A constant supply of water must be provided.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. How do house-heating methods vary in different parts of the United States?
2. Types of humidifiers and what is claimed for them.
3. Test a room for air leakage.
4. Build a fire in a range or furnace and care for it for a day.

REFERENCE BOOKS

ALLEN. *Notes on Heating and Ventilation.* The Domestic Engineering Company.

INTERNATIONAL LIBRARY OF TECHNOLOGY. *Hot Air Heating.* International Text Book Company.

Heating and Ventilation. Catalogue No. 215. Sturtevant Engineering Series. B. F. Sturtevant Company.

CHAPTER XI

HOT-WATER AND STEAM HEATING: CONTROL DEVICES

139. Hot-water heating. In a hot-water heating system, water is heated in a boiler in the cellar. Connecting pipes carry the hot water to the radiators in the rooms and bring the cooled water back to the boiler. An expansion tank is located in the attic. The entire system is full of water.

140. Convection currents. The principle of heat transference from the boiler to the radiators is that of convection. The water in the boiler is always below the boiling temperature, ranging from 100°–120° F. in mild weather to 175°–185° F. in cold weather. The water is about 10° colder when it leaves the radiator than when it enters. This difference in temperature is so small that there is very little difference between the density of the water in the *flow pipe* (that going to the radiator) and the density of the water in the *return pipe* (that returning from the radiator to the boiler). It is this difference in the weight of these two columns of water, however, that furnishes the force to move the water through the system. This difference is not likely to be more than one or two tenths of a pound in any part of the system. The higher the radiator is above the boiler, the greater the difference in the pressures of the two columns of water; consequently, the movement of water through the radiators on the second and third floors will be more rapid than through those on the first floor. This inequality of flow may be corrected by having the pipes going to the upper floors smaller.

141. How the room is warmed. The heat which the water absorbs from the burning fuel is carried by conduction through the metal radiator to the air. The air carries the

heat by means of convection currents to all parts of the room. Considerable heat is radiated directly to the walls and to objects in the room. The room is heated more by convection than by radiation, however, and this, together with the moderate temperature of the radiator, insures a more even heat distribution throughout the room than is given by a stove or by steam radiators. Radiators coated with aluminum or bronze paints containing flakes of the metal deliver only 80% as much heat to the room as they do when painted with zinc oxide, white lead or enamel paints. The color used is not an important factor in heat dissipation.

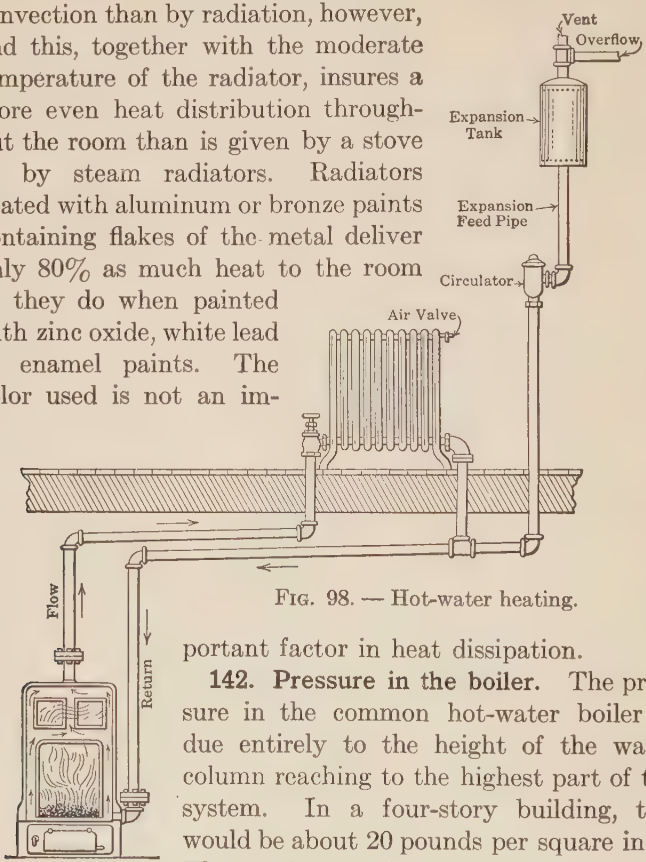


FIG. 98. — Hot-water heating.

142. Pressure in the boiler. The pressure in the common hot-water boiler is due entirely to the height of the water column reaching to the highest part of the system. In a four-story building, this would be about 20 pounds per square inch. The regular cast-iron boilers are not used for buildings over three stories high. If hot water is used in taller buildings, the boilers must be made of wrought iron to stand the pressure.

143. The expansion tank. Since hot water occupies more space than cold water, if cold water, enclosed in any system

of pipes, boiler, and radiators, were heated, the resulting pressure would cause a rupture in some weak spot in the system. To prevent this, a tank, located at a higher elevation than any of the radiators, is connected to the return pipe of the boiler and receives the overflow when the water expands. If contraction results from cooling the water, the tank supplies water to keep the system filled. To make up for leakage or other loss, the supply in this tank is increased from the city supply pipe, which is opened and closed automatically by use of a ball-float valve, which maintains a constant water level in the tank all the time. An emergency overflow leads from this tank to the roof or to the sewer.

144. A cool sleeping room. One drawback to hot-water heating is in its use in the sleeping room. We desire a cold room for sleeping. In mild weather we shut off the radiator part way; this allows a very slow movement of water through the radiators, and does not waste much heat. But should the temperature suddenly go very low, the water might freeze, either in the radiator or in the connecting pipes in the walls of the buildings. It is not safe to shut the radiator off entirely, because of the danger of freezing. The radiator may be left on full with the windows wide open; this will usually give us a cool room, but it is very wasteful of coal. The entire water supply of the heating system will be so cooled that the drafts will need to be opened earlier in the morning to warm the house properly. An effective way of meeting this difficulty is to leave the radiator on full all night, but to prevent loss of heat by wrapping a heavy bed comforter closely about the radiator. This preserves the heat, keeps the water in constant circulation and removes the danger of freezing.

145. Hot-water heating in cellarless houses. A hot-water heater that can be used on the same floor with the radiators, and on every floor of an apartment house, not only eliminates the inconvenience of going to the cellar to tend

the fire, but also saves the expense of building the cellar. Such heaters are in successful use. Satisfactory circulation of water is effected by gravity. The hot water from the

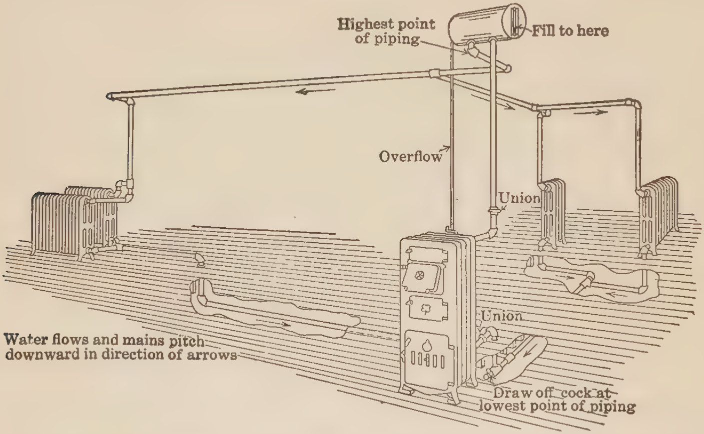


FIG. 99. — A system of hot-water heating with boiler on same floor with the radiators.

boiler goes directly to the expansion tank, thence to the radiators, and then back to the boiler. The boiler itself serves as a radiator in the room in which it is placed.

146. Automatic damper control. Many hot-water boilers are equipped with an automatic device for keeping the water within a narrow range of temperature. As shown in Fig. 100, a mixture of alcohol and water is nearly surrounded by the hot water of the boiler. At 200° F., enough alcohol is vaporized to exert sufficient pressure to lift the weight on the lever arm, and thus to close the draft

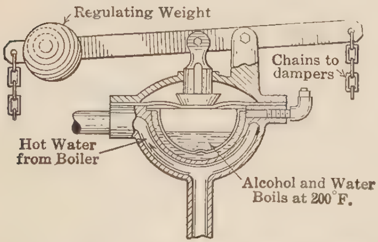


FIG. 100. — Automatic draft control for hot-water heater.

and open the check draft. When the water has cooled a few degrees, the pressure is decreased and the weight falls, opening the draft and closing the check.

147. Combined hot-water and warm-air heating. Some furnaces have water compartments, so that air can be delivered to some rooms and hot water to radiators in other rooms, or both kinds of heat may be used in the same room. Even if the warm-air furnace has already been installed, a hot-water heating disc, which will heat several radiators satisfactorily, may be added to it. The heating power with the water disc is greater in a large firepot than in a small one.

148. Advantages of hot-water heating. In hot-water heating, the radiators may be kept at almost any desired temperature below 180° F. The room is evenly heated throughout, and no dust is brought into it. About 60 per cent to 70 per cent of the heating value of the coal is used. The furnace and boiler require very little attention.

149. Disadvantages of hot-water heating. If the room heated by hot water gets very cold, it takes a long time to warm it. It is difficult to warm radiators on the first floor, if they are far to one side of the boiler. Since hot-water radiators do not get as hot as steam radiators, they must be larger to give the same amount of heat. This system provides no ventilation and cannot be used in tall buildings. The first cost of a hot-water system is greater than that of any other system.

150. Steam heating system. A steam heating plant is, in its main features, like the hot-water system. It has no need, however, of an expansion tank, and the construction of the boiler differs in minor details. The boiler is never filled with water, but a certain space is left for steam; the water level can be seen through a glass gauge.

151. Principles of steam heating. The principle upon which the heating of a room depends is practically the same whether we consider a steam radiator, a hot-water radiator or a stove; but the transference of heat from the boiler to

the radiator differs radically in the case of steam from that of hot-water heating. In hot-water heating the hot water gives up its heat to the radiator *during the process of cooling*. In steam heating, the *steam gives off its latent heat as it condenses* in the radiator. The resulting water leaves the radiator at practically the same temperature as that of the steam entering. The temperature of the steam radiator is usually about 212° F., but if the steam is delivered at

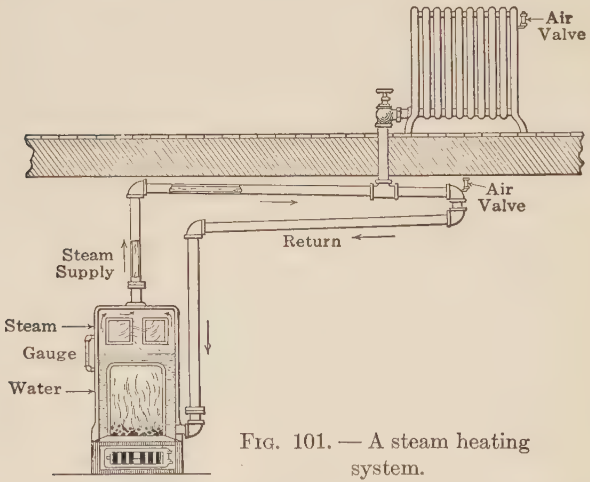


FIG. 101. — A steam heating system.

5 pounds pressure, its temperature is 227° F. About half the heat given to the room by the radiator is transferred by convection and the other half by radiation.

152. Care of the boiler. In order to get as near the full value of the heat as possible, the dust and ashes should be cleaned out of the various cavities of the boiler, where they collect. This dirt is a poor conductor of heat, and when it is left on the surface of the boiler, a hotter fire must be used to produce steam. There are several small doors on the boiler marked "Clean out," and some cleaning can also be done from the large door of the fire-box.

The water in the boiler should be kept clean. Very dirty water will froth on boiling, and will then tend to boil over and thus carry sediment into pipes, which may thus be partially closed and so interfere with the circulation. It is well, occasionally, to draw off some of the water from the boiler. If it is muddy or full of sediment, let the fire go out and draw off all the water. Wash out with more water, then fill.

One of the most common boiler accidents is that of fracture of some of the sections, and one of the most common causes of fracture is low water. The common practice of burning old papers and rubbish in the furnace of the boiler, in the summer, is a bad one. The heat thus produced is very intense and of short duration. The water is at the usual steam level; this keeps the lower part of the boiler cool, while the part above the water line gets extremely hot. The difference in temperature of the two parts causes severe expansion strains, which in many cases result in fracture. If the boiler is to be used as an incinerator in summer, fill it completely with water to prevent unequal heating and expansion.

When building a new fire in a cast-iron boiler, *always make a slow fire,* in order that the expansion of the parts may be gradual and move nearly uniformly. The radiators and pipes are all cold at first, and more than a normal amount of water resulting from condensation will, for a time, be removed from the boiler. If the radiators are cold at night, condensation will draw water from the boiler when it is started in the morning. There is always danger when the water level falls from sight in the gauge glass. If the water in the glass drops out of sight, water must be added slowly until it is visible again. When the return water comes back, it should not rise in the glass out of sight; if it does, some water must be drawn off. If the water cannot be maintained at a level within the limits of the gauge glass without addition and withdrawal, the boiler is too small for the number of radiators in use.

153. Water hammer. When steam suddenly comes into contact with cold water or cold radiators, it condenses, and a vacuum results. If there is water in the pipes with steam pressure behind it, it may move through the vacuum with great speed and strike a hard blow against the iron pipe. A series of blows due to the sudden rushing of water into a vacuum and its striking against the pipe, or other water, results in the pounding, snapping, or rattling in steam pipes, known as *water hammer*. The remedy is to warm up a cold system gradually, or to prevent the collection of cold water in the pipes by suitably placed drip pipes.

154. Systems of piping. Two methods of piping, differing in the way in which the water resulting from condensation is

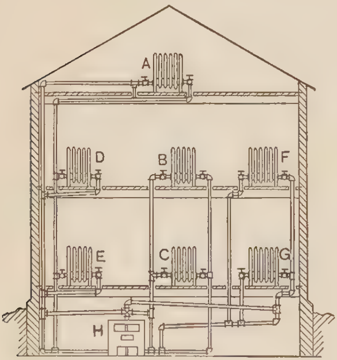


Fig. 102. — Two-pipe steam heating system.

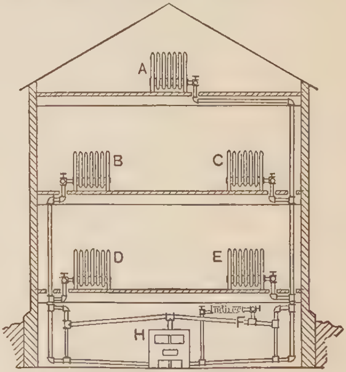


Fig. 103. — Combined one-pipe and two-pipe system.

returned to the boiler, are in common use. These are known as the **one-pipe system** and the **two-pipe system.**

In the one-pipe system the steam passes through a pipe to the radiator, where it is condensed. The water then runs back through the same pipe to the boiler. Since the steam and water are flowing in opposite directions, the pipe should be larger than the one that would be used if the water returned by a separate pipe. Since the water and steam are

in contact, they will be at the same temperature. This removes one of the commonest causes of water hammer. The one-pipe system is very satisfactory for a small heating plant. In a large plant the large amount of water which must be returned makes this system undesirable.

In the two-pipe system the steam passes to the radiator through one pipe, and the water returns to the boiler through a separate pipe. The water will be several degrees colder than the steam. If the steam comes into contact with the water in any part of the system, it will be condensed and form a vacuum, and may be the cause of the water hammer, or snapping, which we sometimes hear when the heat is first started in the morning.

A combination of the two systems of pipe connections is in common use; in this the one-pipe system is used for the vertical pipes and the two-pipe system is used for the horizontal pipes, as shown in Fig. 103. This is, in general, the most satisfactory method of piping for the steam heating system.

155. Advantages of steam heat. In steam heating no dust is carried to the rooms. Because of the high temperature of the radiators, they may be only about two-thirds the size of the hot-water radiators required for the same heating. Distant radiators, as well as those right over the boiler, are easily kept warm. This system is especially suited for warming tall buildings. About 65 per cent of the value of the coal is obtained in useful heat.

156. Disadvantages of steam heat. Direct steam heating does not supply ventilation. Because of the high temperature of the radiator, there is uneven heating of the room. The high temperature, too, causes greater movement of the pipes in expansion and contraction, tending to produce leaks. There is often the disagreeable water hammer noise when the furnace is started. More care is needed in the operation of this system of heating than in either the warm-air furnace or the hot-water boiler.

157. Safety valves. Several devices are used to make the operation of the steam boiler in part automatic, and to insure safety. An unchecked fire, after "steam is up," will quickly increase the pressure in the boiler until a dangerously high pressure results. The boiler is protected by a safety device, which automatically opens a valve and releases the steam when it reaches a certain pressure. The pressure at which the safety valve operates may be what one chooses; it is frequently set either at 5 pounds or 10 pounds. When the safety "blows off," it makes a loud roaring noise, but will do no harm. There is, of course, some heat wasted, and the steam may be objectionable in the

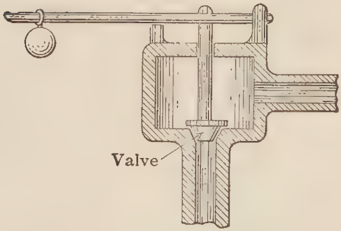


FIG. 104.— Ball and lever safety valve.

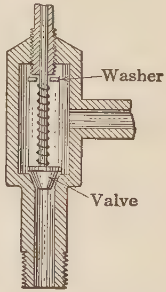


FIG. 105.— Pop safety valve.

cellar. If much water is lost by the escape of steam, water should be added to the boiler to replace it.

The construction of safety valves is shown in Figs. 104–5. In one form, the **ball and lever type,** the valve is held closed by the weight of the ball at the end of the long arm of the lever. The opening pressure of the valve is regulated by the position of the ball on the lower arm. The other, the **pop valve or spring type,** has a spiral spring holding the valve closed. By means of an adjusting screw at the end of the spring, more or less compression is given to the spring, and in this way the pressure at which the steam will blow off is regulated.

158. Pressure gauge. A pressure gauge is attached to the boiler to show the steam pressure in the boiler and radiators. In moderate weather, the gauge may not indicate any pressure, but in cold weather it will be necessary to run with several pounds pressure and to keep the radiators filled with steam.

The operation of the gauge depends upon the action of a curved metallic tube, Fig. 106, closed at one end but with the other end open to the boiler. Through this open end, steam communicates pressure to the inside of the tube. Since the tube is curved, the area of the outer wall surface is greater than that of the inner wall; consequently, this wall will have more pressure exerted upon it and the pipe will tend to straighten. The greater the steam pressure in the tube the greater the movement of the closed end of the tube. The closed end of the tube, which is free to move, communicates motion by action of a lever and cogs to a pointer, which indicates the pressure on a dial. The dial figures signify pressure in excess of the atmospheric pressure.

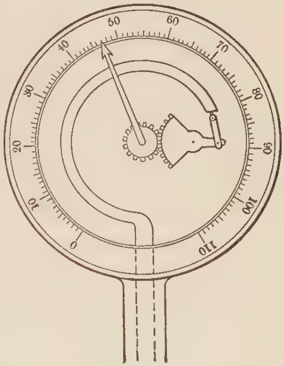


FIG. 106. — Pressure gauge.

159. Radiator air valves. When the steam is first sent into the radiators, the air must be pushed out through the air valves. These valves permit air to pass in either direction when the radiator is cold, but when hot, they are closed, thus preventing steam from escaping. They are automatic in their action. The expansion of a metal pin, when the steam reaches it, closes the opening. People sometimes open these valves to let the air out faster in order to warm the radiator quicker. This is a bad practice because it is a delicate matter to get the valves accurately adjusted again.

If not perfectly adjusted, they will either prevent the entrance of steam into the radiator or permit the escape of steam and overflow of water into the room.

160. Automatic damper regulation. A very useful device is that which automatically closes or opens the draft and at the same time operates the check damper. This device consists of a diaphragm connected to a short pipe which comes out of the top of the boiler. A lever passes over this diaphragm and is held down by a weight, which can be moved along the arm. The position of this weight determines the pressure at which the draft will be closed and the check draft opened. The draft and check are operated by chains, which are connected to the lever arm.

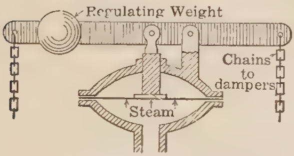


FIG. 107. — Automatic draft control for steam heater.

161. The Percoplate boiler. A new type of steam heater utilizes the percolator principle. By this means only a small amount of water is heated to the boiling point at one time. Consequently, steam can be produced in a shorter time than in the older types of heaters. By reference to Fig. 108, you will see that the water chamber is directly in the hottest part of the combustion chamber. Higher in the furnace are two iron plates with hot furnace gases beneath them. A central pipe leads from the water chamber to the space above the upper plate. These plates are above the water level of the boiler, so that the water not vaporized on the plates flows back to the boiler. Baffles on the plates keep the water from flowing back directly to the water zone of the boiler. The water chamber holds a gallon of water. When this is heated to near the boiling point, it rises through the central pipe and overflows above the hot metal plate at the top of the furnace. Steam is produced here, the excess of water flowing down to the second hot plate where more

steam is produced. The water chamber is supplied with water by connections to the boiler at the sides. The water level is automatically maintained by the supply tank and control on the right. It is claimed that this heater will deliver 75 per cent of the heat of the coal to the rooms.

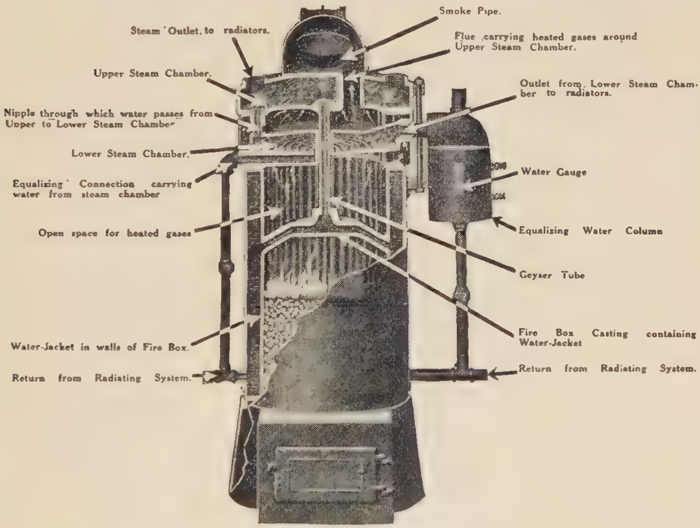


FIG. 108. — The percoplate boiler.

162. Vapor-vacuum and vacuum-pressure systems. In the usual steam heating system, steam, in order to enter the radiator, must overcome the atmospheric pressure to push the air from the radiator. Every time the radiator cools down, air enters and must be pushed out before the radiator can be warmed again. This takes time and requires greater pressure and a higher temperature in the boiler than would be needed if no air were in the system. In a vacuum system, when steam is first produced it forces the air from the system. All the air escapes from the air valve, which is in the basement. There are no air valves on the radiators. When

the steam reaches the controller or air valve after the air has all been ejected, the controller is closed by the expansion of a brass tube. In some systems the air is exhausted by means of pumps, and only a low temperature is needed to fill the radiators with steam at the very start. When all atmospheric pressure is removed from a system, the water will boil at 98° F., and with one-third of the pressure removed it boils at 180° F. The term **vapor-vacuum heating** is commonly applied to those systems which deliver steam to the radiators at or below 212° F. In a **vacuum-pressure system,** a vacuum is maintained in the return pipe and steam under pressure in the flow pipe.

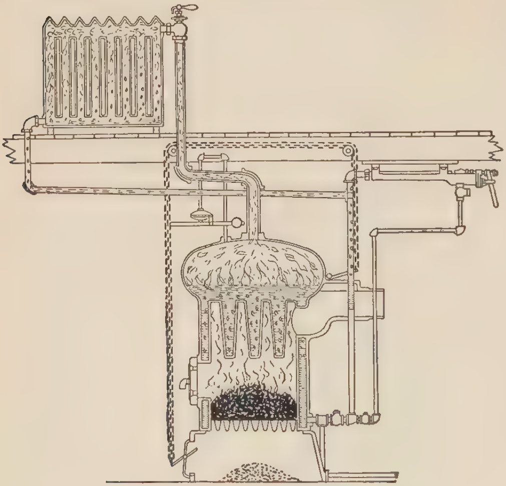


FIG. 109. — The vapor-vacuum system.

163. Advantages of the vacuum system. In this system of heating there is no spitting of water or hissing of steam, both so common with the steam radiator valve. The inlet valve is usually at the top of the radiator and may be opened full by a single turn of the handle. It may be opened part way and the amount of heat regulated to suit the weather conditions.

The vacuum system provides an agreeable heat, much like that from the hot-water system, though it is less expensive to install. It is more economical in its fuel consumption than either steam or hot-water heating.

TABLE XIII

ADVANTAGES AND DISADVANTAGES OF HEATING SYSTEMS

Kind of Heating	Advantages	Disadvantages
Fireplace	Aids ventilation. Low cost. Takes no space.	Low efficiency. (20%.) Uneven heating.
Stove	Low cost. Efficient heating. (70 to 80 %).	Takes much room. Requires much care. Makes dirt and dust. A great fire hazard.
Hot-air furnace	Low cost to install. Aids ventilation. Easy to operate. Temperature changes quickly. No radiators in room.	Large consumption of fuel. Brings dust into rooms. Danger from coal gas. Irregular heating.
Hot water	Small consumption of coal. No dust. Easy to operate. Even temperature.	High cost of installation. No ventilation provided. Danger from freezing. Temperature changes slowly. Radiator space large. Unsuited to tall buildings.
Steam	Small consumption of coal. No dust. Distant rooms easily heated.	High cost of installation. No ventilation. Temperature changes slowly. Radiators take room. Sometimes noisy.
Vapor	Small consumption of fuel. No dust. Temperature changes fairly quickly. All rooms easily heated.	High cost of installation. No ventilation. Radiators take space.

164. Heat derived from steam. In a steam heating system, the heat transferred from the boiler to the radiator is stored in the steam in a latent condition. The amount of latent heat which is thus carried varies, though not in a very important degree, with the pressure in the boiler. The temperature varies, too, with the pressure. Table XIV shows how the properties of steam vary under different pressures.

TABLE XIV

PROPERTIES OF STEAM UNDER DIFFERENT PRESSURES

Vacuum	Temperature	Latent Heat
−10 lbs.	160° F.	1003 B.t.u.
− 5 "	181° F.	988 "
− 4 "	197° F.	977 "
− 1 "	205° F.	971 "
Pressure		
0 lbs. (Atmospheric pressure)	212° F.	966 B.t.u.
2 "	219° F.	961 "
5 "	227° F.	955 "
10 "	239° F.	946 "

It will be observed that the latent heat is greater when water is vaporized at the lower temperatures, and at the lower pressures. One pound of steam under 5 pounds pressure, in condensing, gives out to the radiators 955 B.t.u.; but one pound of steam under 5 pounds of vacuum gives out 988 B.t.u. Under −5 pounds (vacuum of 5 pounds less than atmospheric pressure) the radiator is at 181° F., or about the temperature of the hot-water radiator; but under 5 pounds pressure the radiator is 46° hotter than this. The volume of steam at the lower temperature is greater than at the higher temperature; therefore, in a vacuum system larger radiators must be used than in a pressure system. In the vapor-vacuum system there is less loss of heat by radiation from the boiler and flow pipes, because they are at a lower temperature. The water will boil at 160° F. at −10 pounds or at 181° F. at −5 pounds. Consequently the vacuum system will effect a saving of fuel.

165. The Johnson thermostat. In the Johnson system of automatic temperature control, the thermostat on the wall of the room opens or closes a radiator through the medium of air pressure. Air must be held in a small tank under 10 to 15 pounds pressure, ready for instant use. The thermostat has a compound bar made of two flat pieces of metal soldered together. These metals expand unequally when heated, and so cause the bar to bend. A rise of 2 degrees causes enough movement for the bar to open the air valve, which connects the pipe from the air storage tank to the

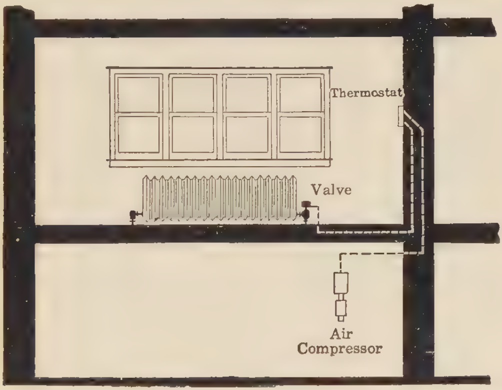


Fig. 110. — Air control of radiator valve operated by thermostat.

pipe going to the radiator valve. The air pressure closes the steam inlet. When the room cools 2 degrees, the end of the compound bar moves in the opposite direction and disconnects the two air pipes, allowing the air to escape from the radiator valve. A spring now opens the steam valve and allows steam to enter the radiator.

166. Thermostat air control. Steam radiator valves are easily operated by compressed air under the automatic control of a thermostat. In Fig. 111, a Johnson thermostat is shown, first closing the valve, and second opening the valve. Compressed air enters the thermostat through the

pipe A. When the port C is opened, a small amount of air escapes through C, but not enough to diminish the pressure to any great extent. The pressure is therefore exerted through the air in D, which is joined to the space above the radiator valve diaphragm. The air pressure closes the

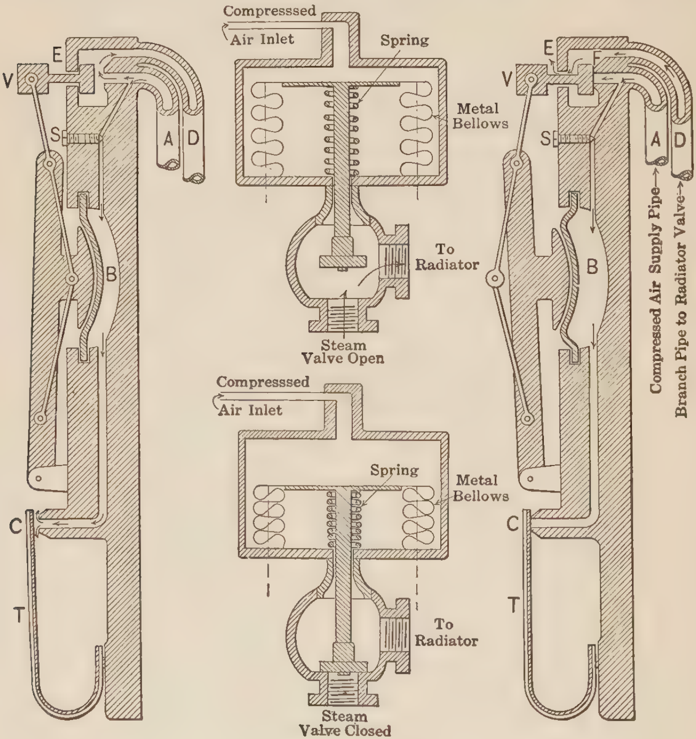


FIG. 111. — The Johnson thermostat control of air-operated radiator valves.

valve. When the temperature of the room falls slightly, the strip T contracts and moves in, so that it closes the port C. The air pressure then increases in B, forcing the diaphragm there outward. This causes the valve V to move in and shut off the air supply. At the same time,

the port E is opened, allowing the air from the radiator valve to escape. The spring inside the metal bellows now raises the diaphragm and opens the valve so that steam may enter the radiator. When the room temperature rises again, the strip T moves out, opening the port C. The pressure on B is removed, and the valve V moves outward. This turns compressed air into D and closes the radiator valve.

167. The Minneapolis thermostat. In the Minneapolis thermostat, a curved strip of metal is fastened at one end and has a long arm extending downward. The lower end of the suspended arm plays back and forth between two set screws. Expansion due to warming causes the coil to open, and the arm touches the right-hand screw. Upon cooling, the coil contracts and the arm touches the left-hand screw. Whenever the arm touches one of the screws it completes an electric circuit which mechanically operates the heat-controlling device. A clock attachment to the thermostat makes it possible to have the heat automatically turned on at an early hour in the morning before you arise.

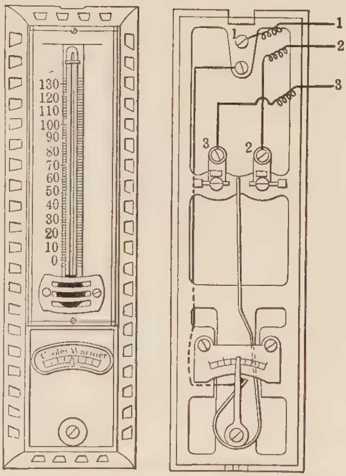


FIG. 112.—This thermostat by closing or opening an electric circuit controls the heat at the radiator or at the furnace.

168. Thermostat motor. In a box near the furnace is a motor driven by a powerful spring, which is wound occasionally. The driving shaft extends outside the box on opposite sides. Chains moving over pulleys connect the drafts, check drafts, and dampers to crank arms on the driving shaft. When the room gets too warm and the thermostat closes the

electric circuit, the electric current from two dry cells operates electromagnets which release the brake, allowing the driving shaft to turn half a revolution; this closes the draft and opens the check draft. When the temperature drops so that the other electric circuit is closed, the brake is again removed and the shaft makes half a revolution, but this time it closes the check and opens the draft. In this way the room temperature can be maintained nearly constant all the time; or, if desired, the thermostat can be set to let the temperature fall quite low at night and be brought up to any desired temperature in the morning.

SUMMARY

1. In hot-water heating, heat is carried from the boiler to the radiators by convection water currents. The room is warmed chiefly by convection air currents, but to some extent by radiation from the radiators.

2. The expansion tank receives the excess of water during expansion and keeps the system full of water when contraction occurs because of cooling or leakage.

3. A hot-water system can be used in a cellarless house by having the hot water flow directly to the expansion tank, from which it goes to the radiators on its way back to the boiler.

4. Hot-water heating gives an even heat, is efficient, and requires little attention. The system is very expensive and it cannot be used for tall buildings.

5. In steam heating, heat is stored in steam in the boiler and liberated in the radiator when the steam condenses. The radiators are much hotter than in the hot-water system.

6. In a one-pipe system, water returns to the boiler from the radiator through the same pipe that delivers the steam. In the two-pipe system, one pipe delivers the steam and another returns the water to the boiler.

7. Steam heating is the best for large, and particularly for tall, buildings. It is much warmer near the radiators than

at a distance from them, because, being hotter than hot-water radiators, they radiate more heat.

8. Steam boilers are equipped with a safety valve, pressure gauge, water gauge, and usually with an automatic damper control.

9. A vapor-vacuum heater is a steam heater in which the air is removed from the system and a vacuum is maintained, at least in the return pipe. In some types the entire system is a partial vacuum, with the result that the water is vaporized in the boiler at a temperature considerably below 212° F. This is an efficient heater and gives a pleasing, even heat.

10. Thermostats keep the room temperature fairly constant. They make use of compound bars which, under a change in temperature, will close an electric circuit or will open an air valve. The electric current or the air-pressure system will then act upon the furnace control, upon the radiator valves, or upon the dampers in the warm-air ducts.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. The heating system of the school building.
2. A plan for improving the heating of my home.
3. Care of the heating plant when not used in summer.
4. A study of a model hot-water heating system.

REFERENCE BOOKS

Allen. *Notes on Heating and Ventilation.* The Domestic Engineering Company.

King. *Practical Steam and Hot-water Heating and Ventilation.* N. W. Henley Publishing Company.

CHAPTER XII

ICE AND REFRIGERATION

169. Sources of ice. Not many years ago, Florida and other states, where the climate is too warm to provide natural ice, secured their supply of ice from Maine and other northern states. The ice was cut from ponds, lakes, and rivers. The harvesting of natural ice is still an important

FIG. 113. — Bringing ice from the field to the ice house. Ice going through the saws.

industry in the north temperate latitudes, but comparatively little is shipped to warmer latitudes. Ice can be manufactured more cheaply than it can be harvested and shipped. The artificial-ice industry has had an enormous growth within the last twenty years, and artificial ice now competes with natural ice even in the cold climate of our northern states. The making of artificial ice is under such control that a more uniform and purer product may be secured, while the quality of natural ice depends upon the source and upon the weather conditions. A pound of artificial ice will give exactly the same cooling effect as a pound of natural ice. Since ice is of such importance in our daily

life, we may well inquire why it is of such value to us. Is it because it is cold? Will a pound of water which is just as cold as ice give us the same cooling effect? Are there any substitutes for ice?

170. Cooling effect of ice. Experiment shows us that when 1 pound of ice at 0° C. is put into 2 pounds of boiling water (100° C.) the temperature which results at the time the ice is all melted is 40° C. If, however, 1 pound of water at 0° C. is used in place of the ice, the resulting temperature is $66\frac{2}{3}$° C. Cooling results because heat is taken by one body from another. Since the ice cools the boiling water more than the cold water does, it must absorb more heat. You probably suspect that this additional heat absorption comes from the melting of the ice.

171. Heat required to melt ice. If two pans are placed on a stove which is evenly heated, and a pound of ice at 32° F. is put into one pan and a pound of water at 32° F. into the other, it will be observed that, at the instant the ice is completely melted, the temperature of the water in the other pan is at about 176° F. We may assume that the ice has absorbed practically the same quantity of heat as the water. Hence it requires as much heat to melt 1 pound of ice as to warm 1 pound of water from 32° F. to 176° F., or 144 degrees. In other words it requires 144 B.t.u. If we had used such small amounts as 1 gram each of ice and water at 0° C., we should have found that it took as much heat to melt the gram of ice as to heat the gram of water from 0° to 80° C., or 80 calories. This is a crude method of measuring heat of fusion, but 80 calories per gram is the result found by more refined methods. These 80 calories of heat are absorbed and become *latent* or *hidden* in the molecules of water, for they produce no rise in temperature. Therefore, when 80 calories of heat are added to 1 gram of ice at 0° C., 1 gram of water at 0° C. is produced.

The heat of fusion of ice is 80 calories per gram.

Expressed in English units, *the heat of fusion of ice is* 144 *B.t.u. per pound.*

PROBLEMS

1. A farmer put 300 lbs. of water at 150° F. into a tub in his cellar on a cold night. In the morning he found that two-thirds of the water had been changed to ice. How much heat (B.t.u.) was given to the cellar?

2. How many calories of heat are necessary to change 50 gms. of ice at 0° C. to steam at 100° C.?

172. Melting points. Most crystalline substances, like ice, sulphur, and salt, when heated until they liquefy, change abruptly from solids to liquids. Such substances have a definite *melting point.* Other substances, as sealing wax, tar, glass, and wrought iron, soften gradually under the application of heat. There is no one definite temperature at which these substances change from a solid to a liquid. If snow is brought from out-of-doors, when the air is at a temperature of −10° C., into a warm room, the snow is first warmed until its temperature is 0° C. A thermometer will indicate this rise in temperature. If we now place this vessel of snow on a hot stove, we shall find that the snow gradually changes to water, but the thermometer does not indicate any increase in temperature. Not until all the snow is melted does the temperature rise above 0° C. Then, as heat is added to the water, the temperature rises.

It is observed that we may have ice or snow at 0° C. or we may have ice or snow and water mixed together at 0° C. If heat is applied, all the solid is first changed to liquid at 0° C. Hence, 0° C. is the melting point of ice. When water is cooled, it is found to solidify or freeze at this same temperature, 0° C., until all the water is frozen. It is possible, however, for pure water which is kept perfectly quiet to cool a degree or so below 0° C. before ice crystals start to form, but if the liquid is jarred it quickly freezes and acquires a temperature of 0° C.

TABLE XV

MELTING POINTS

	Centigrade	Fahrenheit
Alcohol	−130°	−202°
Mercury	−38.9°	−38°
Sea water	−2.5°	27.5°
Ice	0°	32°
Olive oil	4°	39°
Phosphorus	44.3°	111°
Sulphur	120°	248°
Tin	232°	449°
Solder	240°	464°
Lead	327°	651°
Aluminum	657°	1215°
Silver	961°	1762°
Copper	1084°	1983°
Glass	1100°	2012°
Iron, cast	1150°	2102°
Steel	1430°	2606°
Iridium	2300°	4172°
Butter	32°	90°
Lard	36°	96.8°
Soft paraffin	50°	122°
Hard paraffin	58°	136°
Cane sugar	160°	320°

173. Change of volume during melting and solidification. The tremendous expansive force of water during its solidification is brought to our attention when the water pipes freeze in winter. The fact that water expands upon freezing, while it has many features of disadvantage, does have other important advantages. It helps to tear rocks to pieces and so makes soil, and to make the soil better adapted to plant life. The frost in the ground loosens the soil every winter, as may be seen by observing the garden in spring. Since the volume of ice is greater than that of the water from which it is formed, its density must be less than that of water. Consequently, ice floats in water. The expansion is about one-ninth, and so the greater bulk of floating ice is below water. If we freeze 92 c.c. of water, we get 100 c.c. of ice, and the pressure produced when the water is confined is so great that it will burst the thick walls of an iron container. When we freeze ice cream, the can must not be full to the

top, else it will run over while freezing. When the house is piped, there should be numerous cut-off valves in the cellar, so that, in extreme weather, it will be possible to turn off those pipes which are most exposed without interfering with the use of water in other parts of the house.

Type-metal and iron expand upon solidifying. Advantage is taken of this property in making casts. When the liquid metal is poured into the mold, it expands upon solidifying and fills every detail of the pattern. Our coins must be

FIG. 114. — This iceberg rises 200 feet above water and extends approximately 600 feet below water. Seven-eighths of its bulk is under water. This picture, supplied by the U. S. Coast Guard, shows a Coast Guard cutter on ice patrol duty.

made in a stamping mill, because copper, nickel, silver, and gold contract upon solidifying and cannot therefore make satisfactory casts.

174. Freezing mixtures. The common household mixture for freezing ice cream is made of one part coarse salt with three parts crushed ice. Ice in contact with salt melts at a temperature below the melting point of ice alone. The resulting water dissolves the salt. Both the melting of ice and the solution of salt are processes which absorb heat, and this heat must be supplied by the surrounding materials.

The outside container of an ice-cream freezer should be a poor conductor of heat, to prevent heat entering from the outside air. The inside vessel containing the cream to be frozen should be of metal, so that the heat may pass out quickly. Either ammonium nitrate or calcium chloride with ice or snow, produces a freezing mixture capable of yielding very low temperatures. The cooling which results

FIG. 115. — (Left) Stirring ammonium nitrate in water. (Right) Beaker is frozen to the box.

from solution of a salt is admirably shown by mixing 100 grams of ammonium nitrate with 100 grams of water in a calorimeter. Pour a tablespoonful of water upon an empty crayon box and set the calorimeter into the water. Stir the contents and as the nitrate dissolves the calorimeter will freeze to the box.

175. Construction of the refrigerator. The usual household refrigerator is, in principle, a large box with thick, heat-

insulating walls and with doors or covers to the several compartments within. One compartment is for ice. Experience has shown that the best results are obtained when the ice chamber is at the top. The food compartments are below, or sometimes below and on one side of the ice chamber. Refrigerators are styled *top-icing*, *side-icing*, or *rear-icing*, depending upon the arrangement for placing the ice in the ice chamber. All the compartments are connected by air

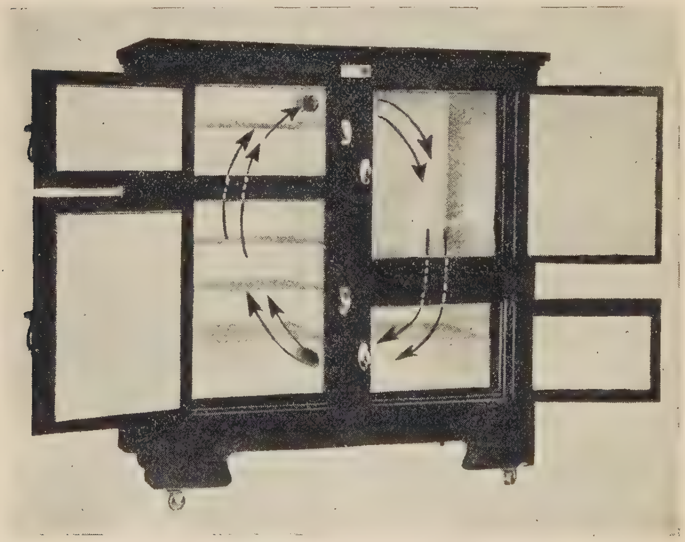


FIG. 116. — Circulation of air in the refrigerator.

ducts so that there may be free circulation of air throughout the entire refrigerator. A drainage pipe leads the water from the ice chamber to a large pan set beneath the refrigerator, or directly to a waste pipe. To prevent outside air or gas from entering through the drip pipe, a *trap* is inserted near the base of the drip pipe. This keeps out the air or gas by means of a *water seal*.

176. The refrigerator wall. Some of the heat that melts the ice in the refrigerator comes from the food, some from

leakage of air around the doors, some from air which enters when the doors are opened; but the greater amount of entering heat which lowers the efficiency of the refrigerator is that which penetrates the walls. The composition of the refrigerator wall is, therefore, of much importance. Refrigerators have double walls of wood between which are various other non-conducting materials, as felt, layers of paper, a packing of mineral wool, sawdust, cork, shavings, "dead air" space, etc. The layers in a satisfactory refrigerator may be as follows, beginning on the outside: wood, felt, air space, sheathing paper, felt, sheathing paper, waterproof paper, wood, air space, porcelain. For heat to enter through this wall, it must penetrate all these substances, and to some extent it will do so in spite of the very excellent insulators used.

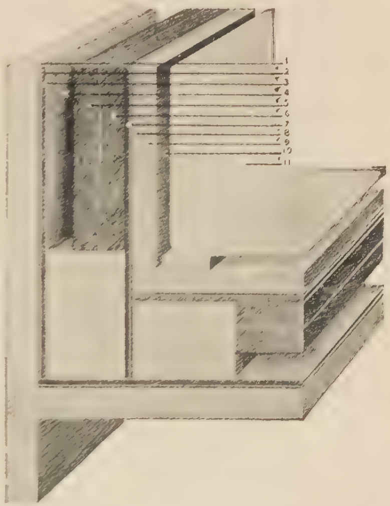


FIG. 117. — Wall construction of a refrigerator. 1. Wood sheathing. 2. Waterproof paper. 3. Woodfelt paper. 4. Air space. 5 and 6. Flaxlinum. 7. Woolfelt paper. 8. Waterproof paper. 9. Wood. 10. Dead air. 11. Porcelain enamel.

177. Air circulation in the refrigerator. Downward convection currents may easily be shown by the following experiment: Invert a cylindrical lamp chimney and clamp it in a vertical position above the table. Place a cube of ice in the upper part of the chimney, supporting it, if necessary, on a piece of wire gauze. Close both ends of the chimney with rubber stoppers having short pieces of glass tubing

passing through them, as in Fig. 118. By testing with smoke, it will be found that a current of air enters the top opening and comes from the bottom tube. If a thermometer bulb is held at the opening of each of the tubes, it will be found that the air flowing out of the lower tube is colder than that entering the upper tube.

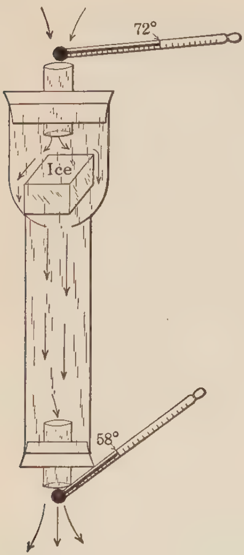


Fig. 118. — Principle of convection in the refrigerator.

When air comes into contact with ice in the ice chamber of a refrigerator, it gives up heat to the ice and becomes colder and denser, thereby sinking to the bottom of the ice chamber. An outlet at the bottom on one side of the chamber permits this dense, cold air to sink through a duct to the bottom of the refrigerator. Warm bodies continually give heat to the air. The refrigerator walls, the partition, and foods are constant sources of heat, for they never quite reach a temperature as low as the cold air from the ice chamber. As the cold air at the bottom of the refrigerator is warmed, it becomes lighter and is forced upward through the various food compartments, absorbing heat all the time. It finally enters the ice compartment at the top, where it is cooled again and starts on another journey through the refrigerator. Each time the air returns to the ice chamber, it gives up its burden of heat, which is carried off, stored as latent heat, in the drip water. Many of the foods give off water vapor, which is absorbed by the air. In the evaporation of water, the food becomes cooler because it loses just as much heat as the water vapor absorbs in changing from a liquid to a gas. Much of this water vapor is condensed to a liquid when the air comes into contact with the

ice. Thus the heat of the water vapor is passed on to the drip water and removed from the refrigerator.

178. Humidity in a refrigerator. Since the capacity of air to hold water vapor is greater at a higher temperature, air in the food compartments of a refrigerator can hold more moisture than it can when it leaves the ice chamber. This gives the air a drying property which prevents the food compartments from becoming damp and moldy as long as there is a good circulation of air. The absolute humidity is lowest and the relative humidity highest in the ice chamber, near the cold air outlet. The relatively dry air passing through the food compartments aids in the preservation of food.

A cubic foot of air at 0° C. is saturated by 2.3 grains of water vapor, but at 10° C. 4 grains are required to saturate it. If a cubic foot of saturated air were to leave the ice at 0° C., and were warmed to 10° C. in the food compartments, it would be able to take from the foods 1.7 grains of water vapor. It would then return to the ice saturated or holding 4 grains, but upon cooling in contact with the ice, it would leave the 1.7 grains of water on the ice. In this way the air acts as a carrier of water from the food compartments to the ice chamber, from which it escapes into the drip pipe. The fact that the air enters the food compartments with low relative humidity accounts for the dryness in the food compartments. If steaming hot foods are put into the refrigerator, more moisture will be given off than the air can absorb. Under these conditions the food compartments become wet, and foods do not keep well. The enormous amount of heat which the steam has stored in it, and which it liberates where the steam condenses, results in a great waste of ice.

In summer a cubic foot of air outside the refrigerator may have 10 to 15 grains of water vapor. When this air comes into the ice chamber, most of the moisture will be deposited on the ice. A cubic foot of air is saturated by 2.36 grains of

water vapor at 35° F. When air is cooled to 35° in the ice chamber, it will deposit any water which it holds, in excess of 2.36 grains. As the cold, heavy air sinks into the food chambers, it is warmed. When half around its course, it may be at 45°. Just before reaching the ice, the air may be 55°, and each cubic foot can hold 4.8 grains of water. It is thus seen that the capacity of the air to hold moisture is doubled by its increase in temperature from 35° to 55°.

179. Where to place food in the refrigerator. The coldest air in a refrigerator is in the bottom of the ice chamber and in the bottom of the refrigerator; the purest air (freest from odors) is where the cold air from the ice chamber enters the food compartment. This air also has least moisture. Certain foods, as milk, butter, and drinking water, if not tightly covered, will absorb odors; they should be placed in that part of the food compartment which first gets the air from the ice chamber. If in vessels that are securely closed, they may be placed in the ice chamber. Uncooked vegetables may be placed on the ice, as they give no odor to the air leaving the ice chamber. Sometimes food placed upon the ice will spoil. The warm air from the food compartment comes in at the top of the ice chamber, and when cooled will sink, so that often the top portion of the food placed directly upon the ice will continually be in warm air, and only the bottom layers will be kept cold. Keep fresh meats at the bottom of the refrigerator. Fish with the skin on may be packed in cracked ice in the ice chamber. If without skin and prepared for cooking, fish should be wrapped in a damp cloth and laid in the food compartment. In moist weather table salt may be kept dry in the refrigerator.

The average temperature, in hot weather, of a well-kept refrigerator, is 50° F. If a lower temperature is desired for any purpose, fill a basin half full of water and place several chunks of ice in this. Enclose the food in a sealed glass jar, and place the jar in the water in the basin. In this way the food may be kept ice cold. Oysters in bulk should be kept

in this way. Some refrigerators have a " wet " compartment which holds water for this purpose. Fruit, eggs, and table " left overs " may be placed on the refrigerator shelf. In a side-icing refrigerator, vegetables should be placed on the top shelf; fruits, eggs, and " left overs " may be placed on the second shelf; meats, milk, butter, etc., at the bottom.

180. Efficiency of the refrigerator. Perishable foods will keep in a refrigerator at 50° F. for several days. They will keep longer at 41° F. or lower. The lowest possible temperature to which the food compartments can be cooled is a

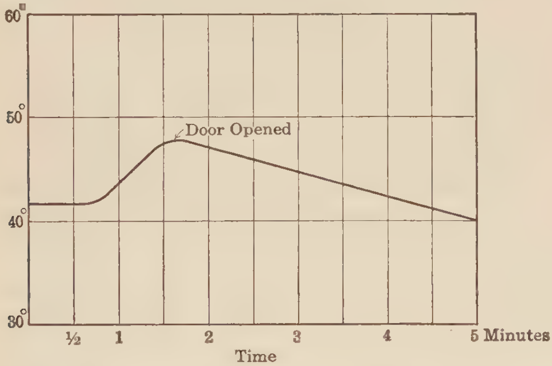


Fig. 119. — Graph to show temperature changes when the refrigerator door is opened and closed.

little above 32° F., but temperatures below 41° F. are not easily or economically maintained in hot weather.

In a " heat-tight " space, foods once cooled would retain their low temperature without further ice consumption, but it is practically impossible to obtain such a space in a refrigerator. Warm air will enter when the doors are opened; it will leak in at the cracks around the doors. Heat is conducted through the walls, for all matter conducts heat to some extent. The heat that leaks into the refrigerator in these ways is usually much more than the heat removed from the foods

The efficiency of a machine *is the ratio of the useful work done to the total work expended.*

In the refrigerator the useful work is the absorption of heat from the food. The total work represents, in addition to this, the heat absorbed from all other sources necessary to the proper working of the refrigerator. If we regard the efficiency of the refrigerator as the ratio of the heat energy taken from the food to the total heat energy gained by the water resulting from melting ice, we find that as a machine, the refrigerator has a low efficiency. Of several refrigerators of the same size, filled with the same foods and with similar outside conditions, that one which will maintain a given low temperature in the food compartments with the least consumption of ice, has the highest efficiency. The efficiency will vary with the quantity and kinds of food, the quantity of ice, frequency of opening doors, the outside atmospheric conditions and construction of the refrigerator.

The heat loss due to entering air depends upon conditions in a specific case and may be judged roughly by a consideration of the following data:

1 cu. ft. air at 86° F. (30° C.) cooled to 50° F. (10° C.) gives 160 calories.
1 cu. ft. air at 77° F. (25° C.) cooled to 50° F. (10° C.) gives 120 calories.
1 cu. ft. air at 68° F. (20° C.) cooled to 50° F. (10° C.) gives 80 calories.

The humidity of the air is even more important to consider, in some cases, than the temperature. For example, 1 cubic foot of saturated air at 86° F., if cooled to 59° F., will give up 9 grains of water. This will give out about 320 calories of heat, or twice as much as the air gives up on cooling.

In a well-made refrigerator, whose doors are practically air-tight, the heat coming to the refrigerator in the air which enters is not especially important, for it would take

75 cubic feet of saturated air, or 250 cubic feet of dry air, to melt 1 pound of ice. But in a poorly constructed refrigerator, even a small leak around the door causes a continual action of convection currents, and will cause a large interchange of air between the outside and the inside, with a resulting large loss of heat.

If large quantities of food of high specific heat are cooled, the useful work is large, but this does not affect the heat leakage through the walls; therefore the efficiency is higher with much food than with little food in the refrigerator. A small refrigerator, well filled with food, is more economical than a large one partly filled, for its efficiency is greater.

A small refrigerator should be considered fairly efficient, if it has an ice consumption of approximately $\frac{1}{200}$ pounds of ice per hour per cubic foot, to keep the empty food compartment 1° F. lower than the outside temperature. On this basis, to keep a food chamber of 5 cubic feet 20° F. below the outside temperature would require 12 pounds of ice, and at 60 cents a hundred, would cost about 7 cents a day. With food in the refrigerator, the cost would be a little more than this.

It is poor economy to run the refrigerator on a small quantity of ice or to wrap the ice in a blanket. If it is desired to keep the ice, wrapping is the thing to do, but in this condition it will not keep the food compartment cool. If the ice does not melt, it cannot absorb heat.

The efficiency of the refrigerator depends to some extent upon its location. A special room just off the kitchen or dining room is desirable for the refrigerator; but it may be in the kitchen or pantry. The cellar is to be avoided because of dampness in summer and the rear porch is open to objection because of the sun and weather. The refrigerator is as well and carefully made as the piano and it should be given excellent care or it will warp, leak, and lose in efficiency.

181. The iceless refrigerator. Natives of hot countries, centuries ago, learned that water placed in vessels made of

porous skins and unglazed earthenware became cooler after hanging or standing in the breeze for a time. The water very slowly penetrated the walls of the vessels and was evaporated at the outer surface. The absorption of heat during evaporation cooled the rest of the water. Many housekeepers know that a bottle of milk, set into a shallow basin of water and wrapped in a wet cloth which extends into the water, will keep better than if placed entirely in the water. Here again, evaporation of water produces cooling. A recent application of this same principle is found in the *iceless refrigerator.* A wood frame of the desired size is covered with galvanized-iron or copper wire netting. The sides are then covered with Canton flannel, which extends into a pan of water set on top of the refrigerator. By capillary action water is carried over the walls of the pan and gravity then carries it down through the meshes of the cotton so that the entire cloth is wet. It is well to have pans under the cloth at the bottom to catch any water which has not evaporated. As the cooling effect is due entirely to evaporation, dry air and wind increase the efficiency of the iceless refrigerator. It is of little value in moist and stagnant air. The air inside the refrigerator is always moist, and so molding is favored. The iceless refrigerator cannot satisfactorily replace the ice refrigerator in hot or humid weather, but during spring and fall it may be used with success. It also makes a satisfactory substitute for a refrigerator at a camp where ice cannot readily be obtained.

A cold window box designed on this principle is often useful. Fasten a metal pan to the sill of a north window. A cloth-covered, wire frame is set into the pan, which has water in it. A non-conducting cover is placed over the top. Keeping the window open usually helps the draft and promotes cooling.

182. Artificial cold. The principle underlying artificial production of cold, whether for ice making, cold storage or any other purpose, on a commercial scale, is simply this.

Certain gases are liquefied under pressure. The heat developed during compression is removed. The pressure is then reduced and the liquid vaporizes. Cold results, because it always requires heat to vaporize a liquid. Heat is further absorbed by the expansion of the gas which results from the vaporization of the liquid. The substances most commonly used in this process are *ammonia, sulfur dioxide* and *ethyl chloride.*

Liquid ammonia boils and also liquefies at −28° F. at atmospheric pressure (15 pounds per square inch). It requires 2 atmospheres to keep ammonia in a liquid state at 0° F.; 7 atmospheres (or 107 pounds per square inch) to keep it liquid at 60° F., and 10 atmospheres (155 pounds per square inch) to keep it liquid at 80° F. If we have liquid ammonia at any pressure above 1 atmosphere and decrease the pressure, the liquid ammonia will change to gas, absorbing heat and lowering the temperature. The degree of temperature possible at any pressure is far below the boiling point for that pressure. Just as alcohol in evaporating may produce a temperature many degrees below its boiling point, so liquid ammonia will, in vaporizing, rapidly produce a temperature lower than −28° F.

183. Cold Storage. Many foods are produced in abundance only for a short period during the year, but we wish to use these foods over a long period of time. Cold storage makes this possible. In all our large cities cold storage warehouses are cooled, either by circulating cold brine in pipes through the rooms where foods are kept, or by having ammonia expansion pipes in the rooms. You frequently see the frost-covered cooling pipes in a fish or meat market.

184. Manufacture of artificial ice. The process of manufacturing ice can best be understood by reference to the diagram, Fig. 120. During the compression stroke of the pump, ammonia gas, which fills the cylinder of the pump, is forced into the cooling pipes. By repeated compression strokes the ammonia gas in the cooling pipes reaches suffi-

cient pressure to liquefy. In liquefying, it gives out heat. The spray of water outside the pipes removes this heat. The cooling pipes are connected with coils of pipe, called *expansion pipe*, in a brine tank. The liquid ammonia passes through an expansion valve into the expansion pipe, which is connected to the pump. During the expansion stroke of the pump, a partial vacuum is created inside the cylinder.

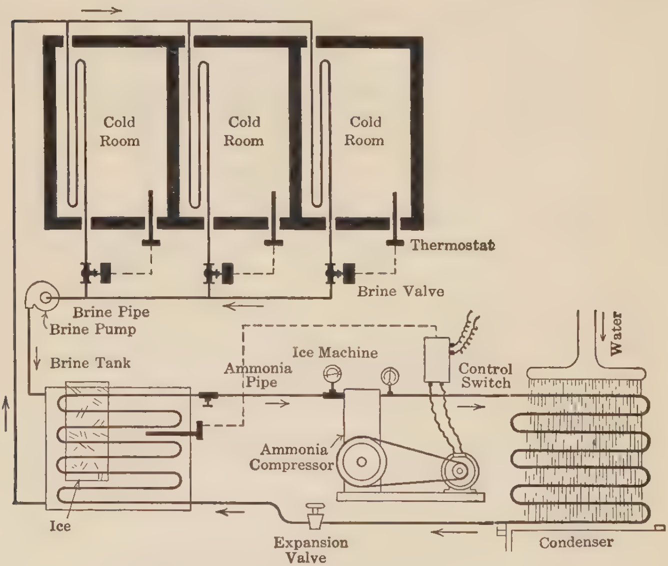


FIG. 120. — Refrigeration plant for cold storage and making ice.

The ammonia gas rushes from the coiled expansion pipe to the pump. As the pressure in this pipe is decreased, more liquid ammonia vaporizes. Both the changing of the liquid ammonia to a gas and the expansion of the gas absorb heat from the brine, which may be cooled to any desired temperature. Metal cans of distilled water are lowered into the brine, which for this purpose is kept at about 16° F. In a large plant hundreds of cans of water are being frozen at one

time. Each can holds 300 pounds of water and requires about 56 hours to freeze solid.

Skating rinks are possible in hot weather by having a series of ammonia expansion pipes a few inches below the surface of the water which, when frozen, is to become the skating surface.

185. Family refrigeration plants. Small refrigeration plants, which can be installed for use with refrigerators in the home, are being used in increasing numbers. They work on the same principle as the large ammonia refrigeration

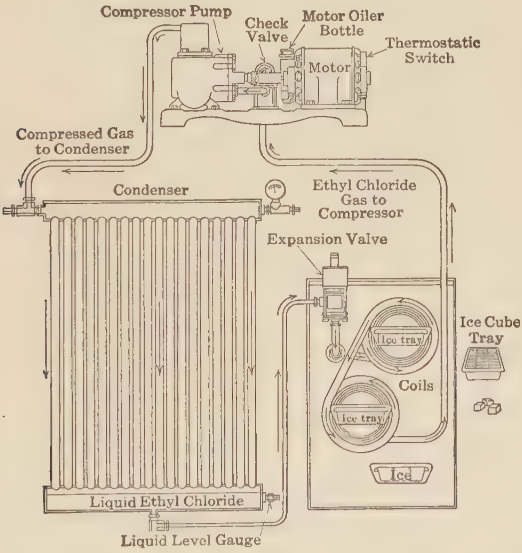


Fig. 121. — A small refrigerating plant for the home. The expansion coils, shown with ice trays are placed in the ice compartment of the refrigerator.

plants, but in place of the ammonia, *sulfur dioxide* or *ethyl chloride* is used. The pump is operated by an electric motor, which is automatically turned on and off as the temperature reaches specific levels. The expansion pipes are placed

in the ice chambers. Trays are provided for making small quantities of ice for freezing ice cream and cubes of ice for drinking water.

186. Ammonia refrigeration in apartment houses. Ammonia refrigeration is used in many large apartment houses. The refrigerators in each apartment are cooled by pipes through which cold brine is circulated. This avoids the nuisance of having to put ice in the refrigerator each day. The refrigerators are kept at a lower temperature than is usual with ice refrigeration.

Ice for special uses is made in open brine tanks in the basement. The brine is drawn from the brine tank, in which are the ammonia expansion coils, and after passing through a pump, is circulated through the refrigerators. The circulating brine varies in temperature from 10° F. to 24° F. The ammonia compression pump is automatically stopped when the brine reaches 10° F. and is started again when it is warmed to 24° F. A single house may have over one hundred apartments, in each of which the refrigerator is cooled by the one plant in the basement.

SUMMARY

1. It requires 80 calories of heat to melt 1 gram of ice at 0° C. and 144 B.t.u. to melt 1 pound at 32° F.

2. Many substances change from a solid to a liquid at a definite temperature, called the melting point. The melting point of ice is 0° C. and 32° F. Liquids solidify at the melting points if heat be withdrawn.

3. Usually a change in volume accompanies a change in state. Many substances, as water, iron, and type-metal, expand upon solidifying.

4. The freezing mixture, salt and ice, produces a low temperature because heat is absorbed when ice melts and when salt dissolves in water. The process is aided by the production of a brine which has a freezing point below that of water.

5. The refrigerator has an insulated space in which air cooled by means of ice may circulate about foods and remove heat from them.

6. A refrigerator well filled with ice and food gives the highest efficiency. Ice must melt in a refrigerator or it cannot absorb heat.

7. Artificial cold results from the vaporization of liquid ammonia and subsequent expansion of the gas. Powerful pumps are used to compress the ammonia gas in order to reduce it to a liquid state again.

8. Artificial ice is made by freezing cans of water in brine cooled by means of coils of pipes in which ammonia is vaporizing and expanding.

9. Refrigerators are often cooled by small refrigerating plants; some of these are only large enough to cool a single home refrigerator.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. Report on a trip to see ice harvesting, to an artificial ice plant, or to a cold storage warehouse.
2. Foods and cold storage.
3. Compare the efficiency of two refrigerators by actual test.
4. Make an iceless refrigerator.

REFERENCE BOOKS

Allen. *Mechanical Devices in the Home.* The Manual Arts Press.
Randall. *Heat.* John Wiley & Sons, Inc.
Smith. *Elements of Applied Physics.* McGraw-Hill Book Company.
Van Rensselaer. *Manual of Home Making.* Macmillan Company.

CHAPTER XIII

ELECTRIC CURRENTS: MAGNETS

187. Electricity and magnetism in everyday life. Few of us pass a day without some experience which brings us into relationship with electricity and magnetism. The electric doorbell, the electric light, the telephone, the electric car, the ignition in the automobile, are but instances of their widespread use. Our town or city gets its standard time daily by telegraph or wireless. We are X-rayed at the physician's or dentist's. Motors do our work, from washing the dishes to milking the cows. It is little wonder that this is called the "Age of Electricity." Living, as we do, in this age, we cannot take advantage of our opportunities unless we understand something about electricity and its uses.

188. Production of current electricity. Just as, in our water-supply system, water flows through the pipes only when there is pressure behind it forcing it along, so an electric current flows through a conductor only when there is *electrical pressure* to force the electric current along. If a small quantity of electricity is required, as in ringing a doorbell, the common **dry cell** is used. To start an automobile a stronger current is needed; this is supplied by a **storage battery.** For our street and house lights, higher pressures and more current are required, and electrical machines called **generators** or dynamos are employed. Millions of dollars are invested in plants which produce current electricity for commercial use. Thousands of generators all over the country make the electric current for electric trains and trolleys, for motor-driven machinery, for our electric lighting and heating devices, and for the majority of our tele-

graph and telephone lines. Current electricity produced by means of cells or batteries is obtained at the expense of chemical energy. Electrical energy from generators comes directly from mechanical energy. The source of the mechanical energy is usually falling water or the burning of coal.

189. The dry cell. The electric cell most used is the so-called *dry cell*. The essential parts of the dry cell are *two plates*, usually zinc and carbon, and an *electrolyte*. Many different chemicals act as electrolytes, but ammonium chloride is the most common substance used. The zinc is in the form of a metal can which holds the other materials. The space between the carbon and zinc is filled with a paste which contains the electrolyte. The composition of the paste in a typical dry cell is as follows:

Ammonium chloride	1 part.
Chloride of zinc	1 part.
Manganese dioxide	1 part.
Granulated carbon	1 part.
Plaster of Paris	3 parts.
Flour	1 part.
Water	2 parts.

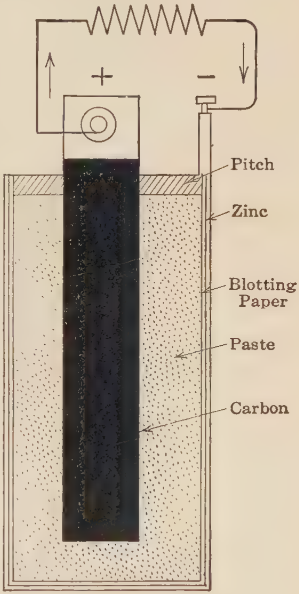


FIG. 122. — Vertical section of dry cell.

The manganese dioxide improves the action of the cell by chemically removing hydrogen, which tends to decrease the current by collecting on the carbon. The moisture is retained in the cell by sealing the top surface with an impervious layer of pitch. The structure of the cell is shown in the sectional diagram, Fig. 122. Each cell is insulated by a pasteboard container. The carbon pole is called the **positive** (+) **pole**, and the zinc, the **negative** (−) **pole**.

As the result of an arbitrary agreement, the current in the outside circuit, or wires connecting the carbon and zinc pole, is considered as flowing from the carbon to the zinc.

Since the electricity results from chemical action in the cell, there is a definite amount of electricity available from each cell, depending upon the materials used and the size of the cell.

190. Electric charges. Every body of matter is composed of atoms. According to a theory now commonly accepted, each atom is composed of a *positive nucleus* associated with *negative electrons.* There is strong attraction between the nucleus and electrons in an atom. These may be separated, however, in a variety of ways. When two bodies, glass and silk for example, are rubbed together, some of the electrons are transferred from the glass to the silk. Because of the excess of electrons on the silk, it exhibits negative properties, while the glass exhibits positive properties, because the positive nuclei have less than the normal number of electrons surrounding them. When hard rubber is rubbed with fur, electrons are transferred from the fur to the rubber, which is therefore negative while the fur is positive. Equal and opposite charges are always produced; that is, the number of electrons gained by one body equals the number of electrons lost by the other body. A body is "charged" electrically either when its atoms have an excess, or when they have a deficiency, of electrons as compared to what they would have in the neutral state. When carbon and metals are placed in solutions which are electrolytes, a similar electrification occurs. This makes it possible to get electricity from chemical cells, of which the dry cell previously described is one type. Bodies with *like charges repel* and those with *unlike charges attract* each other. Both charges attract neutral bodies.

191. Potential difference and electric current. If two insulated metal conductors, *A* and *B*, Fig. 123, are charged alike, but *A* with a stronger charge than *B*, pith balls sus-

pended by threads, after touching the metals, will be repelled, but the ball near A will be repelled more than the one near B. In comparing the two charges, an electrician would say that A is charged to a *higher potential* than B, meaning that it has a higher electrical pressure. If we now bring a metal rod, holding it by an insulated handle, into contact with A and B, we see the pith ball at A fall slightly and the one at B rise slightly until they are repelled equally. The metal rod furnishes a path by which the potentials of A and B are equalized, as shown by the equal repulsion of the pith balls. In the case just given, the equalization was quickly completed, but if some force were constantly at work building up the potential of A, we should have a continuous attempt at adjustment, or "flow," between A and

FIG. 123. — Potential difference and flow of current.

B. The chemical action in a battery continually produces a difference in potential between the two plates. If the poles are joined by a conductor, we express what results by saying there is a continuous flow of electric current along the conductor. This current is assumed to flow from the positive to the negative pole in the external circuit.

192. Water analogy of potential difference. "Water seeks its own level" is a statement that hardly needs comment. If two tanks, A and B, Fig. 124, are joined by a pipe with a valve which is closed, water may be poured into these tanks so that it stands higher in one than in the other. Suppose A has water at the higher level; there is then more pressure on the closed valve in the pipe from the A side than there is from the B side. Consequently, when the valve is opened, water passes through the pipe into the tank B until

the pressure on the two sides of the valve is equal, which is the case when the water levels are the same. In a similar way, two conductors insulated from each other may be charged to different potentials. Let A be charged to a

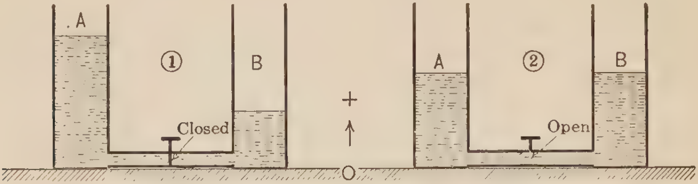


FIG. 124. — Water analogy of potential difference and flow of current.

higher potential than B. Then, if they are joined by a conductor, there is a " flow " until their potentials are equal.

If one of the water tanks, as B in Fig. 125, is below the ground level, water cannot flow out of it, and its pressure

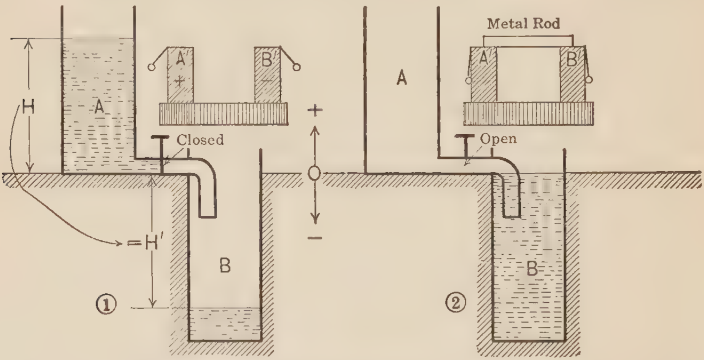


FIG. 125. — When two bodies having equal opposite charges are connected both bodies become neutral. Explain the water analogy.

may be considered a *minus* quantity, measured by H', which is the depth of water required to bring it to the zero level. If tank A, having the same cross section as B, has water standing to a height H equal to H', and is allowed to discharge its water into B, a current of water will flow until

B is full and *A* is empty. *A* will then have no water pressure; neither will *B at the ground level.* When two conductors are charged with equal but opposite kinds of electricity, that is, one is positively charged and the other negatively charged, so that the excess of electrons in one equals the deficiency of electrons in the other, they will repel pith balls with equal strength. But if the two bodies are joined with a metal rod the pith balls drop; no longer are they held apart from the bodies. Why is this? The electrical pressure, or potential, of the bodies has changed to zero, or in other words both bodies are now *neutral.*

What would be the result in the above illustration if H were less than H'? If H' were less than H? Explain the two electrical conditions to fit these two cases.

193. Electromotive force. The two poles of a dry cell, having no connecting conductor from one to the other, or as we commonly say, having the external circuit "open," are at different potentials. The difference in potential is the greatest that the cell can produce and is termed the *electromotive force* (abbreviated e.m.f.) of the cell. When the cell is furnishing current, the difference of potential at its terminals is less than this e.m.f., and is the pressure required to send the current through the *external* circuit only. The potential difference on closed circuit is less than the e.m.f. by an amount equal to the pressure required to send the current through the cell itself.

194. Resistance to an electric current. A given difference of potential causes a definite amount of current to flow through a given copper wire, but if the length or the diameter of the wire is changed, a different amount of current will flow. This is due to the fact that conductors all offer *resistance* to the flow of current. A long wire offers more resistance than a short one of the same sort. A fine wire gives more resistance for the same length than a coarse one. The material also affects the current flow. Iron offers much greater resistance to an electric current than copper of the

same length and diameter. Water will be discharged from a tank more quickly through a short hose than through a long one because of the greater friction of the long hose. It will also be discharged more quickly, that is, there will be a larger current of water, through a pipe of large diameter than through one of small diameter. Do you see how similar this is to the flow of electricity through a wire?

195. Three fundamental electrical units. You probably see that the current which passes in any electrical circuit depends upon the resistance. It also depends upon the difference of potential or electrical pressure. But how do we measure current, difference of potential, and resistance? There must be units for the measurements of electrical quantities, just as there are units for weight, distance, and time.

The unit of current strength is the **ampere,** and is the amount of current which will give a deposit of 0.001118 gram of silver per second when passed through a cell containing a silver salt.

The unit of resistance is the **ohm,** and is the amount of electrical resistance offered by a uniform column of mercury 106.3 centimeters long and 1 square millimeter in cross section, at 0° C.

The unit of electrical pressure is the **volt,** and is the difference in potential between the ends of a wire having a resistance of 1 ohm when 1 ampere of current is passing.

These three units commemorate the names of three famous scientists: Ampère, a Frenchman; Ohm, a German; and Volta, an Italian. Ohm found out the relation which exists among these units and stated it in the form of a law, which has been named after him.

Ohm's Law: *The current in a given circuit varies directly as the voltage and inversely as the resistance.*

This law is conveniently expressed by the equation:

$$\text{Current (in amperes)} = \frac{\text{Pressure (in volts)}}{\text{Resistance (in ohms)}}, \quad \text{or} \quad I = \frac{E}{R}$$

196. The unit of electric power. When we use 1 ampere at a pressure of 1 volt, we consume 1 *unit of electrical power*, namely 1 **watt.**

$$\text{Amperes} \times \text{volts} = \text{watts}$$

Since the watt is so small, the **kilowatt,** equivalent to 1000 watts, is more commonly used. A watt continued for 1 hour gives 1 **watt-hour,** which is the unit of *electrical work or energy.* A **kilowatt-hour** is equivalent to the energy of 1000 watts continued 1 hour.

197. The use of dry cells. The e.m.f. of a dry cell is independent of the size of plates or their distance apart, being dependent only upon the materials used. The amount of current which the cell will furnish, however, depends upon the resistance of the cell as well as upon the resistance in the outside circuit. The larger the plates and the nearer they are together, the less the internal resistance. Decreasing the internal resistance tends to increase the current. The common dry cell, when new, gives an e.m.f. of about 1.5 volts and from 15 to 25 amperes, if its terminals are joined by a conductor of negligible resistance. During use, the chemicals attack the zinc, and gradually both zinc and chemicals are consumed. Dry cells are successfully used for *open-circuit* work, that is, for periodic or intermittent use. If the circuit is closed for a long time, the current diminishes but will recover after the cell stands for a time on open circuit.

A radio battery giving $22\frac{1}{2}$ volts consists of 15 cells, joined zinc to carbon. When connected in this way, the cells are in **series.** When cells are joined in series, the total voltage is the sum of the voltages of the different cells. Great care must be taken to prevent a closed circuit when current is not needed. A wire connection from one pole of the cell to the other will quickly remove the energy and make the cell useless. The small pocket flash lamp frequently has two cells in series. These are connected through the filament of the lamp, but no current flows until the gap in the circuit

is closed by pressing the button or sliding the contact at the side of the case.

198. Closing a circuit. Electricity, at the pressures commonly used, may be prevented from flowing by separating

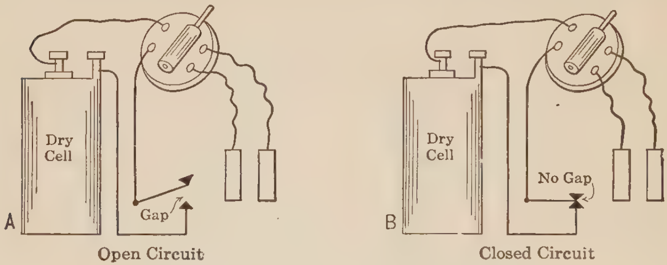


FIG. 126. — Open and closed circuits.

any two parts of the conducting wire in the circuit by a very narrow air gap; but if the air gap is removed by bringing the metal surfaces together, current will flow. There are many different devices for opening and closing an electric circuit. Three common types of circuit closers are the **push button,** which you use to ring the doorbell; the **knife switch,** used to connect the house wires to the outside line wires; and the **socket switch,** used to control individual lights. The button switch can safely carry only a fraction of an ampere and should not be used with a voltage above 15. Wall switches for electric lights are of heavier metal than the socket switches and usually control several lamps. The key of a telegraph sounder is a circuit closer, as is also the telephone plug and jack.

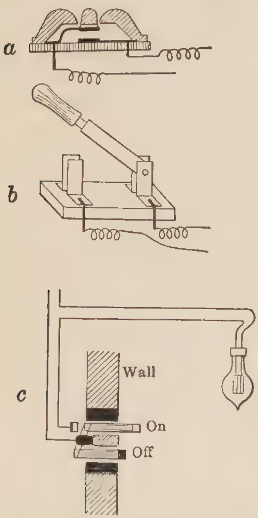


FIG. 127.— Circuit closers. *a.* Push button. *b.* Knife switch. *c.* Wall switch.

199. Conductors and insulators. In order that water may pass through a metal pipe, there must be an open space within. Not so with electricity. In some mysterious way, electricity passes along a solid metal just as well as along a hollow one. Scientists tell us that the flow of electricity is merely the movement of the electrons which are present in the atoms, but this does not make it much clearer to us. There is great difference in the ability of materials to carry electricity. Those substances which permit electricity to pass very readily, as copper, brass, silver, aluminum, graphite, and salt water, are called *good conductors*. Those which carry electricity to a limited extent, as wood, earth, and pure water, are *poor conductors*. Materials which do not allow an appreciable amount of electricity to pass, as dry air, glass, porcelain, rubber, paraffin, mica, and silk, are *insulators*. Metal wires are used to carry electric currents, but they are usually surrounded by cloth or rubber insulation, to prevent leakage and loss of the electricity by accidental contact with other conductors. Insulators also safeguard persons from accidental shock, and buildings from fire, when high pressure current is carried.

PROBLEMS

1. How many amperes of current will be furnished through a wire having a resistance of 1.2 ohms, by a pressure of 10 volts?

2. An incandescent lamp connected across 110-volt mains takes a current of .25 ampere. What is the resistance of the lamp filament when the lamp is lighted?

3. How many watts does the lamp of Prob. 2 consume?

4. At the local rate for electrical power, what will be the cost of operating the lamp of Prob. 2 for 30 days at an average burning of 4 hours per day?

200. Different effects of an electric current. Many different results can be obtained from an electric current. In the household iron, the current produces heat; and in the incandescent lamp, light. The chemical effect of an electric current is used in copper plating, silver plating, and nickel

plating, and in the production of a large number of chemical substances. Every wire conducting electricity is surrounded by a *magnetic field*, which disappears when the current is cut off. Advantage is taken of the magnetic effect of a current to produce motion in the electric motor. Magnetism is of importance not merely because it accompanies an electric current and finds application in many electric devices, but because it is a contributing factor in producing most of our commercial electricity — that coming from the dynamo. The magnetism produced by an electric current has all the properties of that produced by ordinary magnets.

201. Magnetic substances. Magnets attract iron, steel, cobalt, nickel, and some other elements. Iron is the chief constituent of steel, and of all elements it is most strongly attracted by a magnet. Substances which are attracted to a magnet or which can become magnets are *magnetic substances*. Those which cannot be magnetized and are not attracted are *non-magnetic substances*.

202. Magnetic poles. The magnetic effect is strongest near the ends of the magnet. These regions are known as

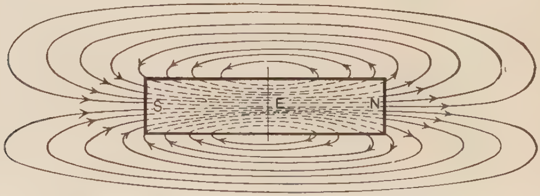


Fig. 128. — Lines of force in the magnetic field which surrounds every magnet.

the *poles*. The place midway between the poles is often referred to as the *magnetic equator*. Either pole of a magnet attracts magnetic bodies. A magnet suspended so that it is free to turn in a horizontal plane, comes to rest in a north and south line. That end which is toward the north is called the **north pole** (north-seeking), and the opposite end,

the **south pole.** *Unlike poles* of magnets *attract* each other, while *like poles repel* each other.

203. Magnetic field. That portion of space about a magnet in which its attractive force can be detected is called the *magnetic field.* This field is represented as being filled with **lines of force,** whose direction is from the N-pole to the S-pole outside the magnet, and from the south to the north within the magnet. The direction may be tested with a compass needle, since the N-pole will point in the direction that the line of force is assumed to take. Iron is a better conductor of lines of force than air; therefore, a piece of iron

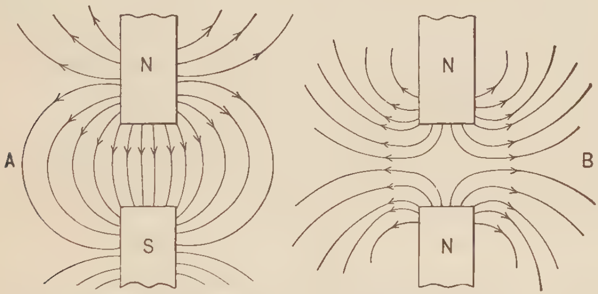


FIG. 129. — *A*. Magnetic field about two unlike poles. *B*. Magnetic field about two like poles.

placed within the magnetic field distorts the field. Likewise, the iron thus placed exhibits magnetic properties, since it has lines of force entering one end and leaving the other end, as all magnets do. This process of magnetizing iron is known as **magnetic induction.**

Theory of magnetism. When a bar magnet is broken into two parts, each part appears to be a complete magnet, each with a north and a south pole. If each part is broken and then each of the subsequent parts is broken, each small piece is also a complete magnet. In our imagination we may carry this division beyond the possibility of actual experiment, to the smallest physical unit, the molecule. It is believed that each molecule of iron is a magnet, and that, when any magnetic force acts upon a bar of iron with sufficient strength to cause many of

these molecules to arrange themselves with axes parallel to each other and N-poles pointing in the same direction, the bar will exhibit magnetic properties. In an unmagnetized bar of iron, the molecules are arranged in groups so that the lines of force are kept within the bar. It is only when the lines of force go outside the bar and create a magnetic field that the bar exhibits the property of magnetism.

204. The earth's magnetism. The compass is a magnet suspended so that it turns freely in a horizontal plane. The earth's magnetism is sufficiently strong to make one end of the compass needle point toward the earth's nearest

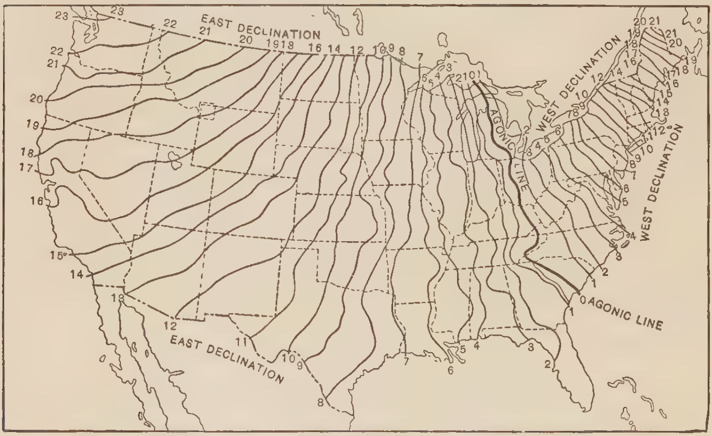


Fig. 130. — Map of magnetic declination.

magnetic pole. The value of a compass lies in the fact that with it you can determine directions when all other means fail. It is thus of great importance in navigation, to explorers, and to surveyors. In most places the compass needle does not point exactly toward the geographic north. This is because the magnetic pole is some thousand miles distant from the geographic pole. The deviation of the compass needle from the true north is called the **angle of declination.** You can learn from a surveyor, how to correct the compass reading for your locality, or you can tell approx-

imately by consulting the map in Fig. 130. The compass needle points toward the geographic pole on the agonic line.

205. Electromagnets. We have already referred to the fact that every electric current is accompanied by a magnetic field. This may be strikingly demonstrated by bringing a wire carrying a direct current near and parallel to a compass needle. By observing the way the needle is deflected, the direction of the lines of force about the wire may easily be determined. The **right-hand rule** will help us to remember the relation of current direction and lines of force. It is this:

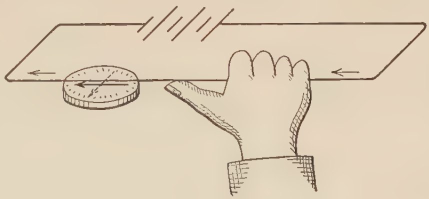


Fig. 131. — The right hand rule for direction of lines of force.

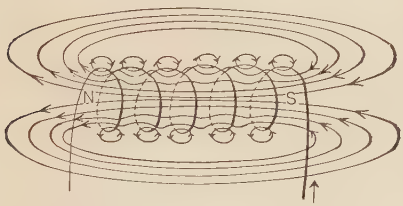


Fig. 132. — Magnetic field around a solenoid.

Grasp the wire with the right hand so that the thumb points in the direction that the current flows in the wire, then the fingers are pointing in the direction of the lines of force about the wire.

When a loop of wire carries a current, lines of force enter one side and leave the other side; thus, each loop has the properties of a magnet

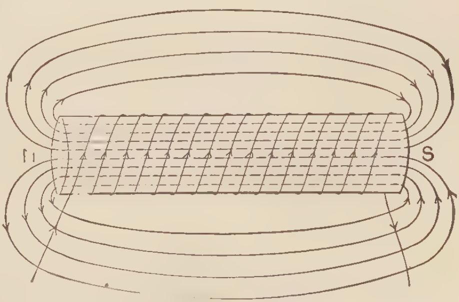


Fig. 133. — Magnetic field around an electromagnet.

with north and south poles. Many loops close together in a coil make a **solenoid.** A solenoid with a soft iron core is an **electromagnet.** The iron core makes a better path for the lines of force, so that they are concentrated inside the coil, and thus make much stronger magnetic poles than could be obtained with the solenoid alone. Here is another right-hand rule for the relation between current direction and polarity of an electromagnet:

If an electromagnet is grasped with the right hand, so that the fingers take the direction of the current, the thumb will point toward the north pole of the magnet.

Electromagnets are of the greatest importance, not only in producing electricity, but also in using electricity, for without them many of our most useful electrical devices would not exist.

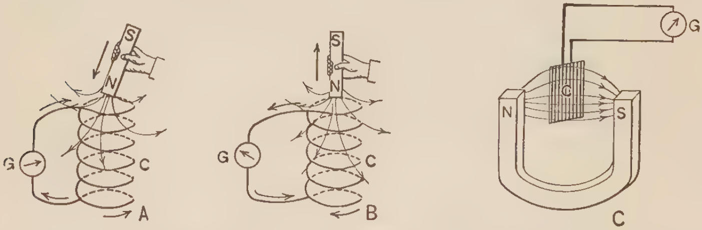


Fig. 134. — An induced current results from relative motion between a closed loop or coil of wire and magnetic lines of force.

206. Electromagnetic induction. We have just learned that when a current flows through a conductor, magnetic lines of force are set up in the surrounding space. Since an electric current produces a magnetic field, we might expect that a magnetic field would produce an electric current, and it can easily be demonstrated that moving magnetic lines of force may produce a current, such a current being called an **induced current.** Suppose we have a closed circular conductor *A*, Fig. 134, and move the north pole of a magnet toward it. A current will result in the conductor, flowing as indicated by the arrow. When the north pole of the

magnet is moved in the opposite direction, the current in the conductor is in the reverse direction, as shown in *B*. Electricity would be produced in just the same way if the loop of wire were moved instead of the magnets. If a closed coil of wire *C*, Fig. 134, is rotated between the poles of a horseshoe magnet, a current is generated and can be detected by means of a galvanometer *G*.

An induced electric current results whenever lines of magnetic force are "cut" by a closed coil of wire.

In other words, any relative motion between lines of magnetic force and a closed coil which changes the number of lines through the coil, produces an electric current. Faraday was the first to discover this fact. This was in 1831, and now, less than one hundred years later, we find application of this principle in all our electric power plants, which make electricity for light and power.

Thus far, we have spoken of a *closed* loop or circuit and of an electric *current*. But we know (§ 191) that an electric current is set up in a conductor by producing *electric pressure.* A more precise way of stating the above would therefore be to say that any conductor moving across (not parallel to) lines of magnetic force *will generate an electromotive force.*

Electromagnetic induction makes electricity the important factor that it is, in our life of today. Thomas Edison was a pioneer in developing the machine which would produce electricity on a commercial scale. The machine is called a *generator* or a *dynamo*. It converts mechanical energy into electrical energy. A simple generator has two magnetic poles, between which rotates a coil of wire called the armature. The ends of this armature wire are connected by means of brushes to the outside circuit. Its essential elements are therefore a magnetic field and a moving coil.

207. How electric current is produced by a generator. Let us try to understand what happens when a single loop of wire is rotated between the poles of a magnet, for if we

understand this we shall have a mental picture of what goes on in the large generators in which hundreds of loops of wire are duplicating the action of this single loop. Suppose the loop of wire in Fig. 135, diagram 1, is rotated in a clockwise direction on the axis xy. As the side AB moves down across the lines of magnetic force, an e.m.f. is induced in it in the direction shown in diagram 2. At the same time, an e.m.f.

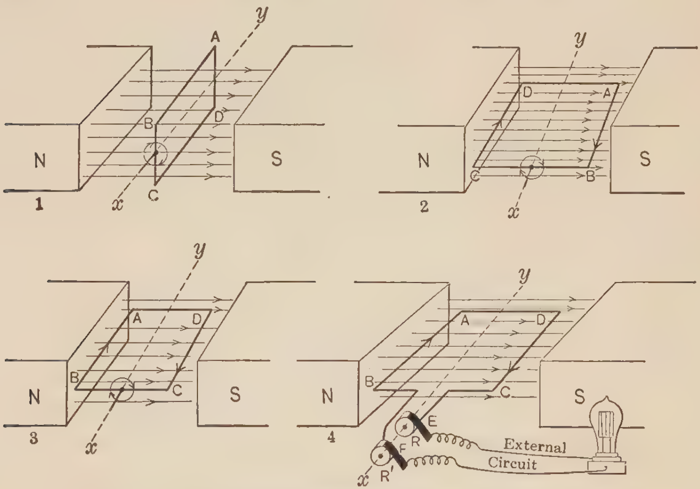


FIG. 135. — Principle of current generation in a dynamo.

is produced in the side CD in the same direction about the loop as that in AB. During the first half rotation, the induced e.m.f. is in the direction $ABCD$. During the second half rotation, it is in the direction $DCBA$, or just the reverse of the first e.m.f. and so on continuously, the induced e.m.f. alternating every half turn.

208. How current is taken from the dynamo. In order to make use of the e.m.f. generated in the rotating coils, or **armature,** of a dynamo, there must be some way of connecting the coils to an outside circuit. The ends of each loop of wire may be joined to a separate metal ring. These

rings rotate with the loop. Carbon or metal **brushes** rest on the rings and are connected with the wires of the external circuit (Part 4, Fig. 135). Since one brush is always in contact with the same end of the wire loop, the current taken off will be of the same character as the e.m.f. generated in the loop — namely, an **alternating current.** Collecting rings are always used on alternating-current dynamos.

When a **direct current** is desired, a split ring, or **commutator,** is used. The ends of the loop are joined to the two parts of the divided ring. The brushes are set opposite each other and come into contact alternately with the two ends of the loop. If the brushes are so placed that they shift from one section of the ring to the other just as the e.m.f. reverses, then one brush will always be positive and the other brush will be negative. Current will always flow *out* from one brush and *in* at the other, as in Fig. 136; thus, although an alternating e.m.f. is generated in the loop, only a direct current passes through the external circuit. Direct-current generators always have the split-ring commutator.

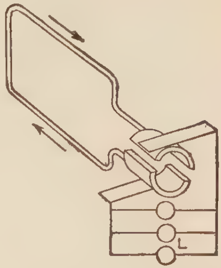


FIG. 136. — A divided ring or segmented commutator.

209. Meaning of "60-cycle A.C." In the loop of wire described in the previous paragraphs, the electromotive force increases as the wire passes through the first quarter of a revolution, that is, from the vertical position to the horizontal, and it decreases during the next quarter turn. During the third quarter turn, an electromotive force in the opposite direction is increasing; this decreases during the last quarter turn. Each wire that describes a circle of 360 degrees in passing the two opposite poles of a magnet has an e.m.f. in one direction built up to a maximum; this decreases to zero and is followed by an e.m.f. *in the opposite direction,* which comes to a maximum and then decreases to zero.

All this occurs during each revolution for every wire rotated. In the graph, Fig. 137, the curve above the horizontal line represents positive e.m.f. A complete cycle is represented by the curve *a* to *c*. Three cycles are represented from *a* to *g*. Suppose the time required for these three cycles is $\frac{1}{20}$ second, then there would be 60 cycles a second. There are 60 positive impulses and 60 negative impulses a second. Where the curve crosses the horizontal line, there is no voltage in the wire, but this period is of such small duration that we do not detect it. A 25-cycle alternating current, sometimes used in arc lamps, gives a noticeable flicker, though an incandescent lamp appears to give a steady light. The common alternating current used for lighting, known as the "60-cycle A.C.," has 7200 alternations per minute; that is,

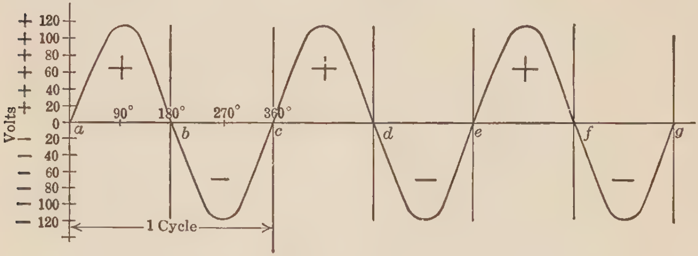


FIG. 137. — Cycles of an alternating current.

the direction of the current throughout the entire length of the circuit changes 7200 times a minute.

210. From the generator to the lamp. The distribution of electrical energy must be done without injury to persons or property and, as far as possible, without loss. It has been found that current can be carried at high pressure with little line loss, but greater care must be taken to secure proper insulation for the high voltage. Dangers of fire, shock, and leakage are largely removed by the use of insulators. Electricity carried at high pressure and low current heats the conductor less than when carried at low pressure and high current. Consequently, electricity is usually carried in the line

wires at a higher pressure than that used in the home. In order to transform electricity from low to high, or high to low pressure, a device called a **transformer** is used. This can be used only with an alternating current.

211. Transformers. The transformer in principle is an induction machine. There are two coils of wire with an iron core in common. One coil, the **primary,** has an electric current from the A.C. generator. Each current impulse builds up a magnetic field, which *induces* a current in the other, or **secondary,** coil. Suppose we have a primary coil of 10 turns of wire and a secondary coil of 100 turns. If a current of 5 amperes at 110 volts is brought to the primary coil, we shall have in the secondary 0.5 ampere and 1100 volts. The voltage increases and the current decreases in the ratio of the turns of wire in the primary coil to the turns in the secondary coil. If the primary coil had 100 turns and the secondary coil 10 turns, we should have, for the above case, 50 amperes and 11 volts in the secondary.

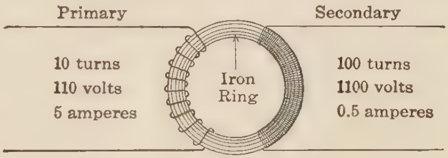


Fig. 138. — A simple "step-up" transformer.

In electric light and power service, which is used many miles from the generating plant, the voltage is raised by a **step-up transformer,** carried over the line wires at high tension (pressure), and reduced by a **step-down transformer** just before it is used in motors or for electric lights. Transformers with several secondary coils are made so that different voltages may be secured for such service as electric door-bells and electric toys.

212. Dangers from electricity. A large number of fires are laid to electricity, and not without good reason, for electrical energy is easily converted into intense heat. When the insulation has worn off an electrical fixture wire,

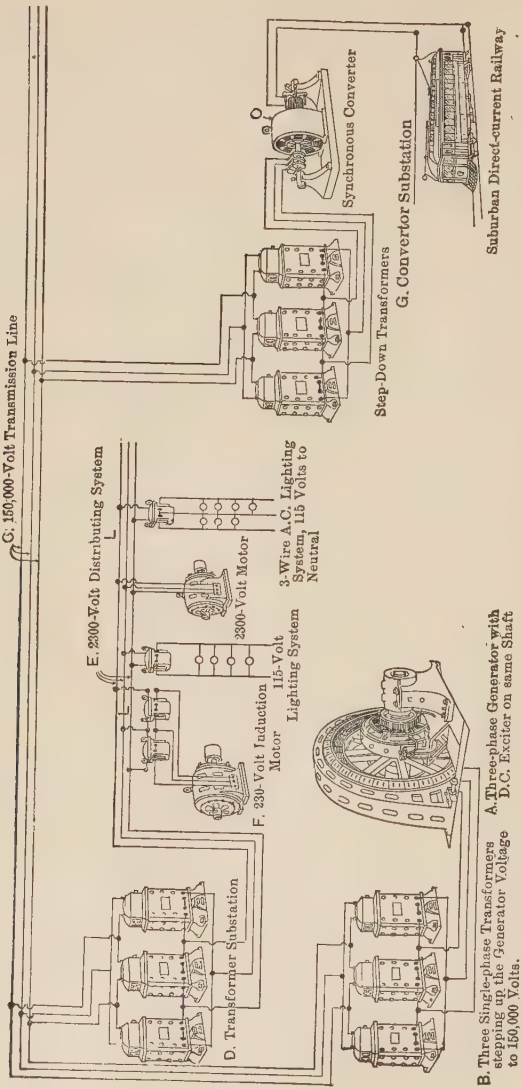


FIG. 139. — A system of commercial transformers, giving the long distance transmission lines 150,000 volts and then stepping it down to safe voltages for lights and motors.

as, for example, a lamp cord, the two bare wires may come together. If they do, sufficient heat to set many materials on fire is produced in an instant. Should a wire be broken and then moved so as to close the circuit loosely, heat and possibly fire will result. Heating devices left uncared for are frequent causes of disastrous fires.

Bodily harm from electricity occurs more frequently than is necessary. This is because of neglect to keep the wire insulation in good condition, and of carelessness about "taking a chance." The resistance of the skin varies with its dryness, being decreased by moisture or greasiness; it also varies with the area which is in contact with an electric conductor. A bare wire carrying our ordinary lighting current at 110 volts or 220 volts pressure may possibly be handled safely if the skin which the wire touches is dry or if the person's boots, by which current leaves, are dry. But let the hand be wet with water or with perspiration, or let the person stand on a damp floor or ground, and enough current may pass through the heart to paralyze it, and cause instant death. Most fatalities from industrial currents come from those at 500 volts to 5000 volts pressure. Curiously enough, people who have received shocks from a 10,000-volt current have lived.

FIG. 140. — This illustrates how many fatal electric shocks have been received.

The external metal of lighting fixtures may come into contact with a wire whose insulation is worn off. A person standing on a carpet may touch the fixture and feel nothing,

or at most only a slight shock. But if the person were in water in the bath or were to touch a water faucet with one hand and the lighting fixture with the other, the shock received might cause death. Higher voltages than 110 are correspondingly more dangerous. No danger results when a comparatively large current flows through the lower part of the trunk alone, but as low a pressure as 65 volts has been known to prove fatal when it passed through the thorax. Birds light on the trolley wire and on the third rail and fly away in safety, because they have made no connection to the earth. You could safely hang from the trolley wire; but if you make any connection to establish a path for the current to reach the earth through your body, you are likely to receive a fatal shock. Hence you are cautioned not to touch any fallen wires, for they may at some distance be in contact with the trolley wire. Guy wires and metal posts sometimes carry dangerous voltages. First aid for electric shocks should take the form of artificial respiration, just as for gas asphyxiation and for drowing.

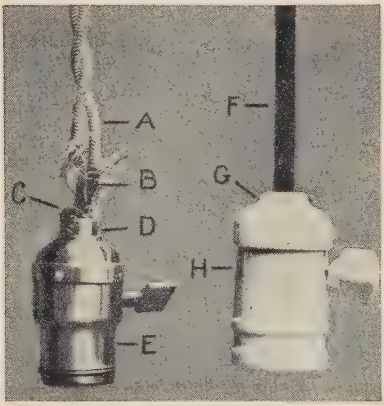


Fig. 141. — Two electric hazards: a poorly insulated cord, *B*, and the metal socket, *E*. A heavier insulation, *F*, a porcelain socket, *H*, and the protecting cap, *G*, are much safer.

SUMMARY

1. Dynamos, which are also called generators, produce electricity from mechanical energy, to supply our great commercial needs. To a small extent, cells, particularly "dry cells," produce electricity from chemical energy.

2. A dry cell contains two plates, carbon and zinc, separated by a paste containing the active chemical, called the electrolyte. The current is assumed to flow in the outside circuit from the positive carbon to the negative zinc.

3. A charged body is one whose atoms have either an excess of electrons or a deficiency of electrons.

4. Difference in potential is the same as electrical pressure. Potential difference, or electrical pressure, causes the current to flow through a conductor. Electromotive force is another name sometimes used for electrical pressure. The electromotive force produced by a cell or generator is greater than the difference of potential of the battery poles or generator terminals when current is being furnished.

5. All conductors resist the flow of electricity. Fine wire offers more resistance than coarse wire. The resistance increases with the length of the conductor. Resistance varies with the kind of matter, iron having more resistance than copper.

6. Three important electrical units are: the ampere, the unit of current; the ohm, the unit of resistance; and the volt, the unit of electrical pressure. The unit of electric power is the watt. The relation of these units is expressed in these formulas:

$$I \text{ (amperes)} = \frac{E \text{ (volts)}}{R \text{ (ohms)}}$$

$$W \text{ (watts)} = I \text{ (amperes)} \times E \text{ (volts)}$$

7. Ordinary dry cells give about 1.5 volts and from 15 to 25 amperes, when new. Joining cells in series — unlike poles together — gives a battery whose voltage is the sum of individual cell voltages.

8. An electric circuit is "open" when there is a break or air gap between two parts of the metallic circuit. "Closing a circuit" consists in bridging this gap by means of some

conducting material. Common circuit closers are switches and " buttons."

9. Materials may be classified as good conductors, poor conductors and insulators, according to their ability to conduct electricity, or to obstruct its flow.

10. Among the important effects of an electric current are: heat, light, chemical action, and mechanical motion.

11. The important magnetic substances are iron and steel. These are attracted strongly by magnets and can be made into powerful magnets. Every magnet has a north and a south pole. Unlike poles attract, and like poles repel each other.

12. The space about a magnet, filled with magnetic lines of force, is the magnetic field. Lines of force are assumed to have a direction outside the magnet from the north pole to the south pole. A piece of iron in this field becomes magnetized by induction.

13. The earth is a huge magnet. Its magnetic field directs the compass needle. The needle does not in all places point toward the geographic pole, because the magnetic and geographic poles are not in the same place. The angle between the compass direction and true north is the angle of declination.

14. A coil of wire carrying an electric current is called a solenoid; a solenoid with a soft iron core is an electromagnet.

15. An induced electromotive force results whenever there is relative motion between magnetic lines of force and a conductor. This is the principle underlying the generation of electricity in the dynamo. Alternating-current generators use collecting rings, and direct-current generators use a split-ring commutator to transmit the current from the armature to the brushes and through them to the outside circuit.

16. In a 60-cycle alternating current there are 60 positive impulses and 60 negative impulses of electricity a second. This makes 7200 alternations per minute.

17. A transformer for increasing or decreasing the voltage of an alternating current consists of two coils of wire upon the same iron core. It is a step-down transformer if the primary coil has more turns of wire than the secondary. It is a step-up transformer if its primary coil has fewer turns of wire than the secondary. Either or both of these types may be used in the distribution of current for electric lights.

18. Defective insulation upon electric-light wires is responsible for many fires. Shock from electric-light wires may produce fatal results. Fixtures which give a shock when they are touched have defective wiring inside and ought to be repaired. First aid in lightning or other electric shocks should take the form of artificial respiration, as for drowning.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. What I saw at the electric power station.
2. Substitutes for the magnetic compass.
3. Determine the energy used by an electric iron.
4. Test the voltages obtained by different connections on a bell-ringing or other step-down transformer.
5. Determine the horse power of a household motor.
6. Lantern lectures, *Development of the Electrical Industry.* (Lecture No. 14.) *The Electric Motor and its Application.* (Lecture No. 20). Lectures and slides loaned by the General Electric Company.

REFERENCE BOOKS

Good. *Laboratory Projects in Physics.* The Macmillan Company.
Milliken and Gale. *Practical Physics.* Ginn and Company.
Packard. *Everyday Physics.* Ginn and Company.
Smith. *Elements of Applied Physics.* McGraw-Hill Book Company.
Timbie. *Elements of Electricity.* John Wiley & Sons, Inc.

CHAPTER XIV

ELECTRICAL DEVICES IN THE HOME

213. The house electric circuits. From the generator, the electric current passes through the street lines into a transformer, from which it emerges at a pressure considered

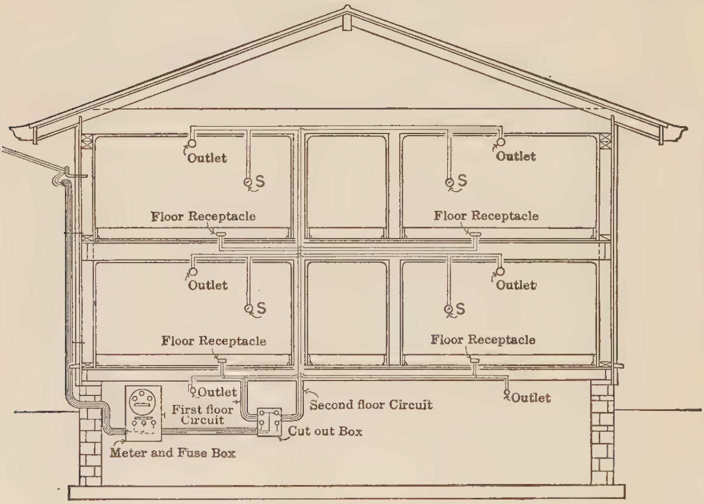


FIG. 142. — House circuits.

safe for household use. Wires from insulated supports on the side of the house enter the garret or basement and are joined respectively to the fuse box, main switch, meter, and distributing box, with circuit fuses. From the distributing box, several circuits lead to different sections of the building. Each circuit is designed to supply a certain number of lamps and outlets for other purposes.

The locations of the lighting fixtures and of the outlets for connecting electrical equipment in a house are of such importance that they should be given careful consideration in

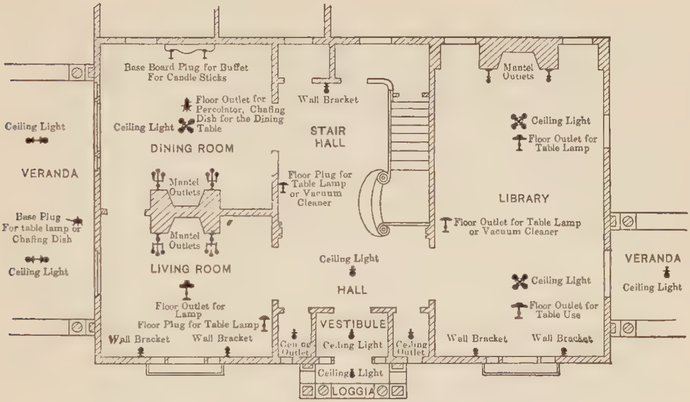


FIG. 143. — House plan showing electric outlets.

planning the house. Many of you have observed, especially if you live in a rented apartment, how poorly lighted some

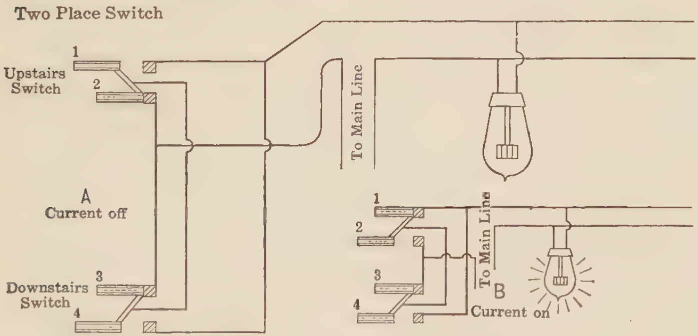


FIG. 144. — Wiring connections of a two-place switch.

rooms are and how much inconvenience is caused by the lack of outlets for attaching the vacuum cleaner, heating devices, or an electric fan. A large room is lighted by lamps

in different parts of the room better than by a single, large lamp in the center. Light from many sources prevents annoying shadows and gives a pleasing, diffused light which is not so tiring to the eyes. The location of control buttons is another important matter to consider in drawing up the house wiring plan. The double switch for lighting a lamp from two different places, as two opposite entrances to a room, or from upstairs and downstairs, deserves more frequent use, as it is a great step saver. You may find it interesting to follow out the working action of this switch, as disclosed in the diagram in Fig. 144. In the best practice, concealed wires are all enclosed in flexible metal cable which removes the danger from fire.

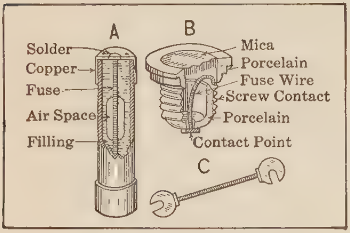


Fig. 145. — Three types of fuses: cartridge, socket and link.

214. Fuses. Fuses have an important place in the electric equipment of the home, although few people even know of their presence. Their purpose is to act as a safeguard against harm which might otherwise result from a short circuit. If any piece of metal were accidentally to make connection across the two wires coming, for example, to the heating device from the house circuit, a strong current would flow through this metal, as it would short circuit the house wires by cutting out the heating device. This current would be far in excess of what the heating device would allow to pass through the conducting wires. As a result, the wires might become so heated as to cause fire somewhere in a partition of the house; but if a fuse were installed where the wires first come into the building, such a catastrophe would be averted. The fuse wire, which is an alloy of soft metals of low melting point, is made a part of the house circuit. A current that is great enough to cause fire will melt the fuse

and break the circuit, with the result that no more current can flow until a new fuse is installed. It is an easy matter for any careful person to install a fuse, and every girl should learn how to do it. *Open the main switch before putting in a new fuse,* in order to avoid all danger of shock. In order to test an old fuse to see if it is good, connect the two metal parts of the fuse as shown in Fig. 146. If the bell rings the fuse is good.

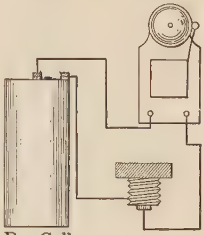


FIG. 146. — How to test a fuse.

215. Use of electric heat. Because of the advantages of readiness, cleanliness, and convenience, electricity is fast becoming a popular source of heat. Only the cost prevents its more general use. Some electric companies make a lower rate for heating than for lighting. This can well be done because the demand for current for heating comes largely at a time when little current is being used for lighting, and thus utilizes the electric plant for a longer time each day without causing an excessive " peak " load at certain hours. The most popular home device employing heat derived from electricity is the *electric iron.* The various *table devices* are next in popularity. There are toasters, grills, coffee percolators, chafing dishes, samovars, and plate warmers. The immersion *water or milk warmer,* and the small *disc stove* are useful and economical when only a small amount of heat is required. The *electric range* is in common use in some sections of the country where a rate of from 2 to 6 cents a kilowatt-hour can be secured. The electric *curling iron* and hair drier are comforts to some, as is also the *electric pad.* The *glowing electric radiator* gives both cheer and warmth and in a measure replaces the fireplace of other times.

216. Efficiency of electric heating. Electricity cannot compete with coal, wood, or natural gas for general house

heating. A pound of coal gives 14,000 B.t.u. at a cost of about one half a cent for the coal. Suppose one-half of this heat is lost and only 7000 B.t.u. are utilized; at 2 cents a kilowatt-hour, electricity would cost 4 cents. Electrical energy can be converted into heat with practically no loss. Electric heating devices are therefore about 100 per cent efficient as far as transforming the electrical energy is concerned, but there is a large loss in energy in producing the electricity from the coal. Moreover we cannot apply all the heat from an electric heating device to useful work. The nickel-plated electric iron at its best gives only about 85 per cent of usable heat. Even at the greater cost per heat unit, there are times when electricity may be more economical than other sources of heat. This is particularly true when only a small amount of heat is needed. Heat from electricity can be applied just where it is needed with the least possible loss. Coal and wood are particularly inefficient when a large fire must be built for the purpose of heating a small quantity of water.

217. The electric heating element. In every conductor of electricity some electrical energy is changed to heat energy. In good conductors this change is small, but in conductors whose resistance is high it is large. There are metals and alloys which are far more resistant to the passage of electricity than copper or iron, and which do not oxidize when heated in the presence of air. Two of these alloys have been given the trade names "nichrome" and "chromel." They are alike, however, in composition. In the heating elements for electric ranges and furnaces, the very best alloy, consisting of 80 parts nickel and 20 parts chromium, is used.

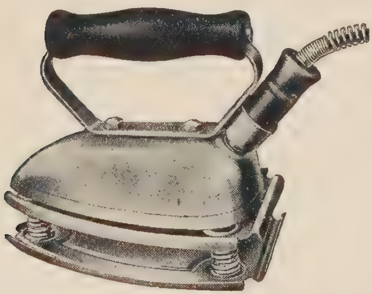


FIG. 147. — The electric iron.

In flatirons, toasters, and similar devices, a nickel-iron-chrome alloy of the following composition is used: 63 per cent nickel, 25 per cent iron, and 12 per cent chromium. If a nichrome wire is bent into many loops, so that a very great length can be placed in a small area, a heating element will be produced. The wire used in a heating element, in addition to having a high resistance, must have a very high melting point, and it should also resist oxidation. In many devices the wire is embedded in an insulating enamel. The heating element of an electric iron is shown in Fig. 148.

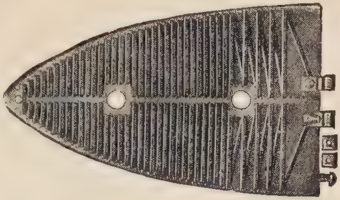


FIG. 148. — Heating element of the electric iron.

218. The electric toaster. In the common electric toaster, the wire is not enclosed in enamel, but instead, the bare wire is arranged in loops in front of a rack which holds the slices of bread. The wire is of such size and length that the regular lighting current will heat it red hot. The heat is radiated directly to the bread, which is quickly browned.

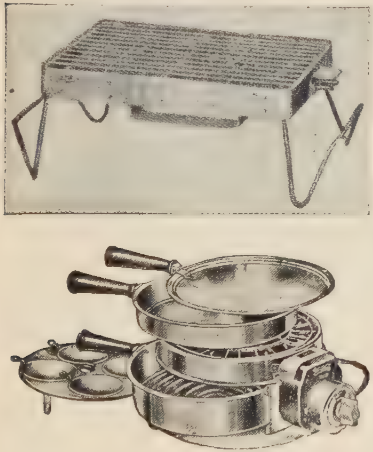


FIG. 149. — Two types of electric grills.

219. The electric grill, or broiler. Intense heat is required in broiling. This is obtained in the electric grill through rows of coiled, bare wires which make up the heating element. When the wire is red hot, an intense heat is produced. The hot wire is protected by the

guard wire net, which prevents the conducting coils from being accidentally touched. All wires that are used at very high temperatures are relatively short lived.

220. Electric radiators. The early forms of electric radiators were of the type commonly found in electric cars — spirals of wire carefully insulated, heated to a relatively low temperature as compared with that required in cooking devices. Because of the low temperatures required, the life of the radiator is long. The luminous radiator and the glow heaters have the advantage of cheerfulness, if no other. The luminous radiators contain powerful lamps, giving both heat and light. These are backed by metal reflectors, and the direct light is diffused by frosted glass. The glow heater, like the bread toaster and grill, has coils of bare wire heated to the glowing point in air. The coils are made of nichrome or some similar alloy of very high resistance. Close to the coils are blocks of glazed fire-clay which reflect the heat into the room. There is much direct radiation as well as heating by convection.

221. Electric ranges. The electric range is the equivalent of several disc stoves, any one or all of which may be used at one time. The oven has heating elements above and beneath. The entire oven is protected against heat loss by insulating material, on the same principle as the fireless cooker. The electric range requires, on the average, about one and one half kilowatt-hours for each person in the family per day, but it is very easy to use much more power than this. A 600-watt stove may heat a dish of water to the boiling point in twelve minutes. After the water is once boiling, only 125 watts are needed to keep it hot; it is easy to neglect to change to the lower heat. In baking, high heat may be needed for half an hour, and then low heat will be sufficient to complete the baking, or perhaps the current could be cut off entirely.

Most ranges, some irons, and other devices are provided with a " tell tale " light. Whenever the current is on, the

pilot lamp glows. A glance is then sufficient to tell whether or not the current is turned off. Compensation for the higher cost of heat from electricity is found in the absence of much of the drudgery and other objections which accompany other forms of heating. The ash can, coal hod, wood box, with

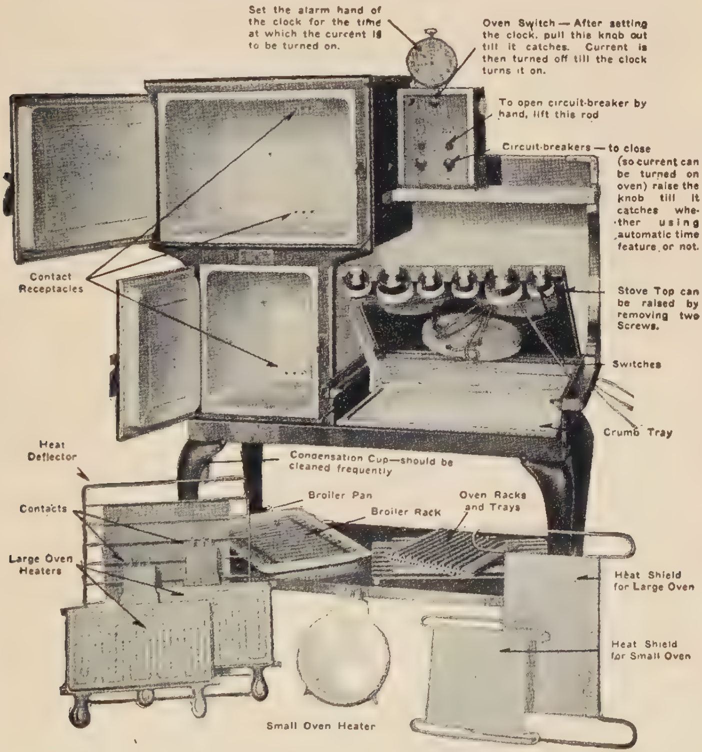


FIG. 150. — An electric range.

all the other dirt, the smoke, and the burned gas, are not found in the electric kitchen.

222. Other heating devices. The hot-water tank may have an electric heating attachment by which the water is heated as it enters the tank. One form of a water-heating

element consists of an iron pipe surrounded by closely wound resistant wire embedded in enamel. The water is heated as it passes through this pipe.

The electric pad, or bed warmer, makes it possible to warm the bed without delay or long preparation, and by the same device heat can readily be applied to any part of the body. The pad is flexible and adapts its shape to that of the body, and heat can be had for any length of time desired. The pad contains wires which are carefully insulated by a covered asbestos, which is also a safeguard against fire.

Electricity is particularly well adapted for heating incubators and brooders, because the amount of heat can be regulated with accuracy. There is perfect distribution of heat, no gaseous fumes, and little danger of fire. At the average cost of electricity, the expense is more than with kerosene, but the time and attention saved more than balance the account.

Heating elements placed inside curling irons, soldering irons, in the base of glue pots, sterilizers, etc., add to the cleanliness and convenience of many common processes.

223. Cost of heat from electricity. Many cities and towns charge a lower rate for electricity used for heat than for that used for lighting. When this is done, two meters, with separate circuits, must be installed in the house. All heating devices must be used on the heating circuit. Electric heating on an extensive scale, at the regular lighting rates, is too expensive in most places, in comparison with the cost of common fuels, for common use. Lighting by electricity is not much more expensive than lighting by other means, and much less energy is used for lighting than is required for heating. In some cities a sliding scale of price is used; for example, 3 cents per kilowatt-hour is charged for the first 100 kilowatt-hours each month, and $1\frac{1}{2}$ cents per kilowatt-hour for all used in excess of that. The amount of electric power required for various forms of household electrical equipment is shown in Table XVI.

Table XVI

ELECTRIC POWER USED BY HOUSEHOLD APPLIANCES

Device	Watts
12-inch electric fan	40
3-pound iron	250
$6\frac{1}{2}$-pound flatiron	525
Toaster	400
Coffee percolator	500
Small hot-water boiler heater	1500
Washing machine $\frac{1}{4}$ H.P.	300
Ice-cream freezer $\frac{1}{2}$ H.P.	500
Sewing-machine motor	200
Vacuum cleaner	200
Electric range oven	2500

224. Electric pressure and heat. The electrical pressure of lighting circuits varies in different places from 110 to 130 volts. Through a given conductor more current (measured in amperes) passes at a high than at a low voltage; and, since the heating effect *varies* directly *as the square of the current*, an increase in voltage makes a rapid increase in heat. An electric heating device is made for a specified voltage. The range of variation in voltage for successful use of the electric iron is small. Too low voltage means too little current and so insufficient heat. Too high voltage means increased heat and the possibility of melting the resistant wires and thus ending the use of the device. Whenever a new heating device is secured for home use, make sure that the range of voltage specified for that particular device covers the voltage of the city current in use.

225. Light from electricity. By far the most important application of the heating effect of an electric current is that in which the heat is so intense that light results. You well know that an iron bar held in the furnace coals gets so hot that it glows with light as do the coals themselves; and so it is with the metal filament in the electric lamp. The hotter the filament of an incandescent lamp can be heated, the greater the efficiency of the lamp in changing electrical

energy to light energy, because of the larger proportion of short or light wave lengths in the radiation. The old-style carbon filament could be heated safely to 1930° C. The tungsten filament in a vacuum will stand 2150° C., and in a gas-filled bulb, 2500° C. The gas prevents evaporation of the filament by putting pressure upon it, much as pressure on water raises the boiling point. This higher-temperature operation is the reason for the greater efficiency of modern, metal-filament lamps.

226. The incandescent lamp. The only incandescent lamps of importance manufactured today are tungsten lamps. The filament in a 25-watt lamp is about $\frac{1}{3}$ the diameter of

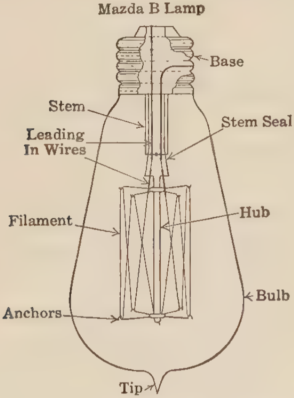


FIG. 151. — Our common incandescent lamp.

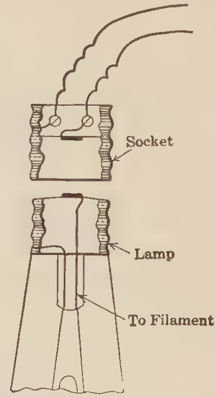


FIG. 152.— How the lamp filament is made a part of the electric circuit.

a human hair and is $1\frac{1}{2}$ feet long. The oxygen is removed from the bulb to prevent oxidation of the filament. Lamps, when purchased, are marked with the voltage at which they should be operated. When used at a lower voltage, they give much less light and so have low efficiency. When they are burned at a higher voltage than they are rated, the filament gets too hot and the life of the lamp is decreased. It is therefore very important to secure lamps with the

proper voltage rating for the circuit in which they are to be used.

227. The night light. Sometimes one desires to have a low light burning all night. There are two types of lamps for this purpose. One of these employs a transformer which is enclosed in the base of a tiny, 2 candle-power lamp; the other employs a resistance which can be thrown into the circuit to cut down the strength of the current.

228. Heating-device troubles. When we fail to get results with a heating device, the trouble may be with the device itself or it may be in the circuit which should bring the electric current to the device. To locate the trouble in any case, it is well to be familiar with the entire circuit. Usually connection is made to the lighting socket, or to a similar wall receptacle, by means of a plug which pushes or screws into the receptacle or socket. The receptacle has two metal parts which make contact with the metal parts of the receptacle. The extension cord leading from the plug to the device holds two wires carefully insulated from each other. The insulation must be removed from the ends of the wire when they are attached to the plug. The wires may become loose in the plug, increasing the resistance, or the bare wires may come into contact and "blow" a fuse. The cord itself, when used a long time, may have one of the wires broken in it, or the insulation may be worn through so that the two wires come together, forming a short circuit which will blow a fuse. When the device does not work, the trouble may be that the wire connections are loose or a wire is broken, the power is off, a fuse is blown, the terminals of the heater or plug are corroded or burned off, the plug is not screwed into the receptacle far enough, the switch connections are poor, or the heating element is burned out. In this last case, it is possible with some devices to secure a new heating element from the dealer. The remedy in other cases is usually simple and easily applied by any one who has a little patience and ingenuity.

229. The electric bell. One household use of the electromagnet is found in the *electric bell.* The source of current is usually a battery, though it may be a transformer which steps down the city lighting current. The cost of using current from the lighting supply through the transformer is about the same as that for the renewal of batteries. In the diagram of the electric bell, Fig. 153, follow the electrical connection through the system. Starting at the battery, the current goes to one binding post, to the push button, to the contact post, to the armature, to the coil of the electromagnet, and then to the other binding post of the battery. When the button is pressed and the circuit thus closed, the current creates a magnetic field about the electromagnet. The soft iron armature is then drawn toward the magnet and the clapper strikes the gong. After the armature has been drawn a short distance toward the magnet, it is separated from the contact post. This breaks the circuit. The current ceases, the magnetism disappears, and the armature is brought back to its original position by the spring at its end. This closes the circuit once more, and the action

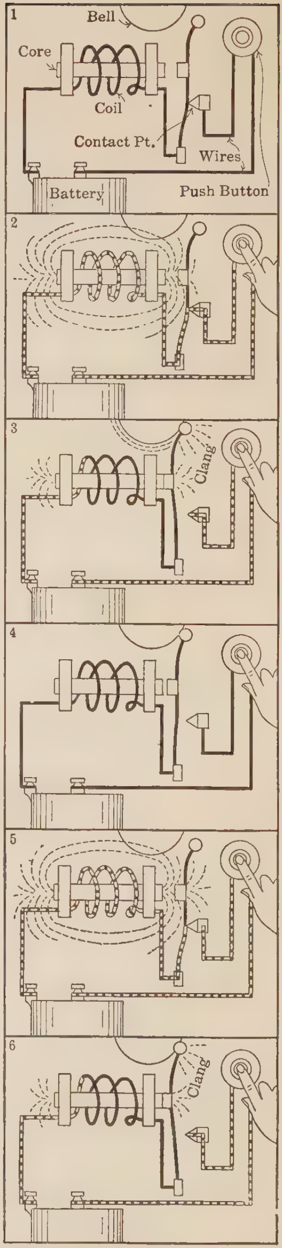


FIG. 153. — Movie of "Ringing an electric bell." Describe each picture.

just described is repeated. This action continues as long as the button closes the circuit.

230. Bell troubles. If the bell does not ring, clean the wire connections and fasten them securely in the binding posts at both bell and battery. If it still fails to ring, failure is usually due to one of four things: a weak battery, a broken wire, a short circuit, or improper adjustment of the contact screw. When the battery is weak from long use, it must be replaced. If a break in one of the wires occurs, you must locate the place. This is easily done as follows: join a bell in the circuit, close to one pole of the battery; keep the push button on closed circuit. Using a short wire with bare ends as a test wire, follow the pair of wires from the battery toward

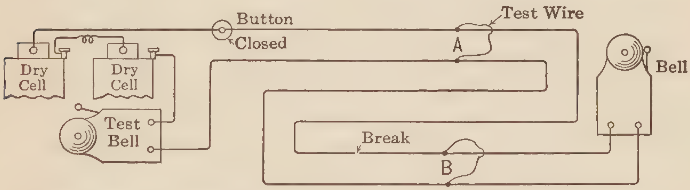


FIG. 154. — Testing the bell circuit to locate a broken wire.

the bell, testing at intervals by removing a little of the insulation and joining the two wires with the test wire. The test bell will ring until you go beyond the broken wire. In Fig. 154 the bell will ring with the wire at *A*.

The bell may fail to ring because of a short circuit. For example, if the two wires are fastened under the same staple, the insulation may wear through in time, and the staple may make a short circuit, thus preventing the current from reaching the bell. To test for a short circuit, place a bell in circuit as in testing for a broken wire, and close the button; the ringing of the test bell indicates a short circuit, and the wiring must be inspected until the short circuit is located. The contact screw sometimes loosens and needs to be advanced slightly and tightened. Sometimes dust col-

lects on the contacts, and cleaning the points is all that is needed. To make sure the trouble is not in the push button, unscrew the cap and examine the wire connections there.

231. The telephone. We are indebted to Alexander Graham Bell for working out a practical telephone system. The two essential devices which make it possible to talk with a person miles away are the **transmitter** and the **receiver.** There are other devices in the local equipment; for example, the call bell, an induction coil, and a condenser. To complete a call through "central" involves many complicated connections, wiring, and devices. The ease with which we communicate with distant friends gives no suggestion of the difficulties which have been overcome in preparing the system that makes this possible. It is a new idea to many people that the telephone does not transmit sound. Sound is vibration of matter. This vibration is carried through the air in waves and these waves cause other bodies to vibrate. In the telephone, the transmitter converts sound waves into *pulsations of electricity* which, through the agency of the receiver, are transformed back into sound waves.

232. The telephone transmitter. The telephone in its present form uses many devices very different from those invented by Bell. The transmitter in use today is the invention of Blake, who applied the discovery that pressure on granules of carbon changes their resistance to an electric current. By reference to Fig. 155 you will readily understand the arrangement of parts in the common carbon transmitter.

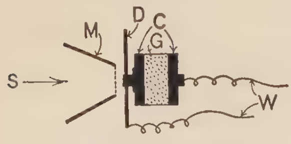


Fig. 155. — Telephone transmitter.

Sound waves — vibrations in the air — come into the mouthpiece of the transmitter. These set the thin metal diaphragm vibrating. Every forward swing of the diaphragm compresses the carbon granules; every backward swing removes the pressure, thus allowing the carbon granules to separate a little. Suppose a current of electricity

is flowing through the carbon granules all the time. When they are compressed, their resistance is decreased and the current is increased. When the pressure is lessened, the resistance is increased and less current flows. Thus you see that a sound wave, which makes the diaphragm move back and forth, causes the current in the circuit to vary in unison with the vibration of the sound wave, with the result that a pulsating current passes through the circuit. This pulsating current must be carried to the receiver at the other end of the line.

233. The telephone receiver. The receiver, as will be seen from Fig. 156, has a permanent magnet with one end wound to form an electromagnet. Dolbear was the first to use a permanent magnet for the core of the electromagnet in the receiver. The action of the permanent magnet is so superior to that of the electromagnet with a soft iron core that permanent magnets are found in all the millions of telephone receivers that are used daily. Just in front of the electromagnet is a soft iron disc, or diaphragm. The production of sound takes place as follows: The fluctuating, or pulsating, electric current from the transmitter passes into the primary of an induction coil. This produces an alternating current in the secondary coil, which passes into the electromagnet coil of the receiver. The permanent magnet is alternately strengthened and weakened in unison with the sound waves which make the transmitter diaphragm vibrate. The receiver magnet, as a result of this varying strength, causes the diaphragm, which is close to it, to vibrate. This sets the air in front of it into vibration, and sound results.

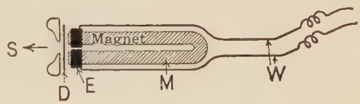


FIG. 156. — Telephone receiver.

234. The motor in the household. The use of electricity to perform mechanical work in the modern home is greater than one would at first suspect. The electric motor drives

the pump or fan of the vacuum cleaner; it operates the clothes washer, the dish washer, and the clothes wringer. The electric fan is motor-driven. Nowhere does the electric motor give more satisfaction than in the sewing machine. The motor is also used, though less frequently, for operating the ice-cream freezer, for grinding and polishing, and for other kitchen operations. In rural homes it has other valuable uses, such as pumping water, running the cream separator, shelling corn, cutting ensilage, etc.

235. How a motor works. In structure, a motor is like the dynamo; in fact, most dynamos will run as motors.

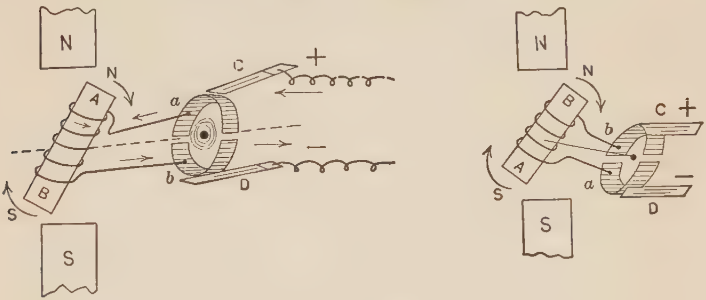


FIG. 157. — Principle of a simple electric motor.

Mechanical energy is transformed by the dynamo into electrical energy, but the motor changes electrical energy into mechanical energy. Motion in the motor is brought about by magnetic action. In Fig. 157, current is brought through brush C to the segment of the commutator a and returns to the circuit through segment b and brush D. It passes around the soft iron core of the armature AB, in such a manner that the end A, which happens to be near the north pole of the field-magnet, is made a north pole. Repulsion between the two north poles immediately occurs. Repulsion is also taking place between the two south poles at the other side of the armature. The south end B is attracted to the north field-magnet and the north end A is attracted to

the south field-magnet. Motion results from this attraction. Since the armature and the commutator rotate on a common axis, when half a revolution has been made, brush C is in contact with B and brush D with A, and as a result B is north and A is south. As a result of this change in polarity of the armature, the rotation, which was begun the previous half turn, is continued, and continuous rotation is produced by the change in direction of the current in the armature every half turn. For alternating currents, a motor without brushes or commutator is used; this is called an **induction motor.** Small motors are now made which may be used with either the alternating current or the direct current.

236. The electric car. Although the electric car can hardly be called an electrical device of the home, yet it is

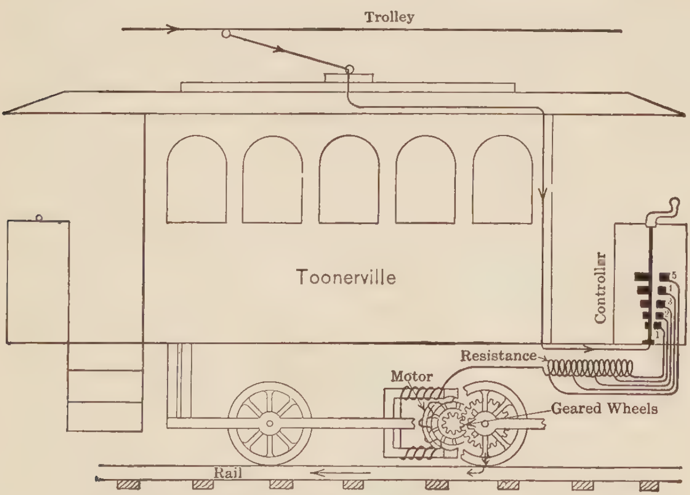


FIG. 158. — Electric circuit through the trolley car.

a device that enables many people to have their homes in a much-desired location, by furnishing them cheap transportation to and from business. The current is generally supplied from the power house, through a trolley wire or a

third rail. The trolley wire may be overhead, or it may be underground, as it is in the City of New York. A difference of electrical pressure of about 600 volts between the trolley, or third rail, and the track rails, is maintained. When the motorman starts the car, he turns the controller handle, which, little by little, takes out the resistance through which the current flows when the circuit is first closed. The removal of resistance is a means of sending more current through the motor. When the car is to be stopped, the current is switched through the resistance coils again before being cut off entirely. The complete circuit from the dynamo in the power house is as follows: to the trolley wire; to the controller and resistance coils; to the motor; to the rails; and back to the dynamo again. When the ends of the rails are joined together with wire cables, there is much leakage of the electricity into the ground, and nearby water pipes may carry the return current and become corroded. Much energy is saved by having the rails welded together.

SUMMARY

1. The house electric circuit includes many different parts besides the connecting wires, as: main switch, meter, distributing box and fuses, outlets and buttons or switches to the devices that are used.

2. Fuses are made of low-temperature melting metals. Their use in an electric circuit is to cut off the electricity when a short circuit produces excessive heat, which might cause fire.

3. Electric heat is popular because of its cleanliness and convenience. Only its high cost prevents it from being used more widely. The heating elements are composed of resistance wires, usually made of nickel-chromium alloys.

4. Heating devices are made for use with an electric current with a rather narrow voltage range. Lower vol-

tages give unsatisfactory service. Higher voltages shorten the life of the heating element.

5. The most important purpose of electric heat is to make light. The tungsten filament can be heated nearly 200° C. hotter than the carbon filament in a vacuum bulb and nearly 600° C. hotter in a gas-filled bulb. Better light and more efficient change of electrical to light energy is secured by heating to the higher temperature.

6. When an electric device fails to work, the cause may be found in a loose connecting screw, a broken wire, insulation in the contact points, a blown fuse, or a burned-out heating element; or the power may be shut off.

7. The action of the electric bell is due to an electromagnet which draws an armature, with hammer attached, forward to strike a gong. In so doing it breaks the circuit, removing the magnetism and allowing the armature to return to its normal position, where it closes the circuit and then repeats its former movement.

8. Bell troubles may be due to: (1) a weak battery; (2) a broken wire; (3) a short circuit; or (4) improper adjustment of the contact points.

9. In the telephone transmitter, a box of carbon granules is placed in the circuit, so that sound vibrations will alternately subject them to greater and to less pressure. This decreases and increases the current, causing a fluctuating current to go to the receiver.

10. The telephone receiver receives the fluctuating current in a coil of wire around one end of a permanent magnet. Weaker and stronger magnetic fields are set up, corresponding to the strength of the current. Magnetic action causes a diaphragm to vibrate and thus send out sound waves which duplicate those striking the transmitter diaphragm.

11. Mechanical motion in an electric motor is the result of magnetic action. Properly timed electric currents through the armature commutator produce attraction and repulsion, resulting in continuous rotary motion.

12. The electric car circuit is: power house; trolley wire; motor (with or without resistance in circuit, depending on the position of the controller arm); rails; and back to the generator in the power house.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. Make a plan of the house wiring at home. Indicate the fuses for each branch circuit, and locate all lamps and outlets belonging to each circuit.
2. High-tension electric transmission.
3. Report on a visit to the telephone exchange.
4. Test to see which costs more to run — an electric radiator or a gas radiator.

REFERENCE BOOKS

Good. *Laboratory Projects in Physics.* The Macmillan Company.

Lancaster. *Electric Cooking, Heating, and Cleaning.* D. Van Nostrand Company.

Packard. *Everyday Physics.* Ginn and Company.

CHAPTER XV

LIGHT A FORM OF RADIANT ENERGY

237. What is light? Since man first began to think about natural phenomena there have been many ideas about light. Several theories have been set forth to explain what light is. At the present time, it is believed that light is a form of energy transmitted by ether waves which are capable of reacting upon our eyes to produce the sensation of sight. The *ether* which bears these waves is that intangible, weightless something which fills all space. It is between the molecules of matter and fills the space between the heavenly bodies. Vibrations in this ether constitute waves. All ether waves do not produce light. Heat energy and electrical energy are also a part of the radiant energy transmitted by ether.

238. Radiant energy. Radiant energy is a term applied to any form of energy that is transmitted by means of ether waves. Experiments have shown that ether waves vary in length and in the number of vibrations per second. Different waves produce different effects. Very long ether waves carry *electricity*, used in the transmission of wireless messages. Shorter waves give us *radiant heat*, and still shorter waves, which affect the eye, are classified as *light*. Next come the waves which are too short to affect the eye, but which cause chemical action on photographic plates and in photosynthesis. These are in part *ultraviolet rays*, which are also known as *actinic rays*. The *X-rays* are ether waves much shorter still, while the shortest waves known are sent out by radium. The vibration rates of these various ether waves are given in Fig. 159. The speed of ether waves is 186,000 miles per second. This is equivalent to 300,000,000

meters per second. The frequency, or number of vibrations per second, may be determined by dividing 186,000 by the wave length expressed in miles or 300,000,000 by the wave length in meters. Some of the electrical waves are miles in length, while the short X-ray waves are of microscopic dimensions.

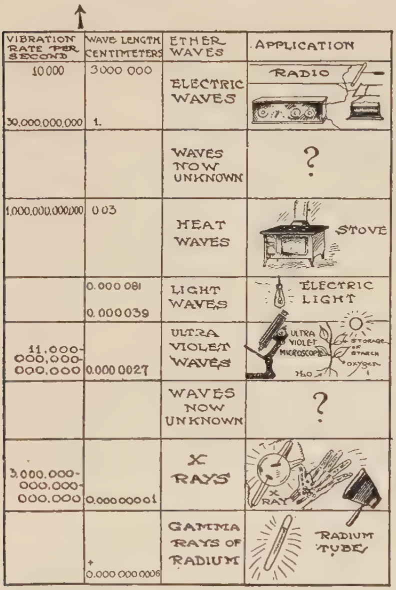


FIG. 159.—Range of ether waves.

239. Light waves. You are familiar with the circular waves produced whenever a pebble is dropped into water. The water rises and falls (transverse vibration) as the wave moves outward, ever making a larger and larger circle. Light waves are transverse vibrations in the ether; but unlike the water waves, which spread out in a circle in one plane, the light waves are spherical in form. From any luminous point, waves pass off in spheres, which continue to increase in size until they meet some obstruction which deflects or absorbs their energy. Radii of these spheres represent the direction of motion of the waves, and any radius represents a part of the wave. That part of a spherical wave represented by a single radial line is called a **ray** of light. A group of rays make a **beam** of light.

240. What becomes of light? When a beam of light meets any kind of matter, three things may happen to it. It may be *reflected*, *transmitted*, or *absorbed*. Practically all substances reflect some light; highly polished surfaces and

mirrors reflect much more than dull, black surfaces do. Non-luminous bodies are seen only by the light which they reflect. Thin paper and oiled paper, which transmit enough light to permit bodies to be seen indistinctly through them, are called *translucent* or *semi-transparent* bodies. Glass, clear mica, and pure water transmit a large amount of light and permit objects to be seen distinctly through them. They are *transparent*. Iron, wood, earth, and brick do not allow light to pass through them. Such bodies are *opaque*. Conditions may change the classification of substances in these three groups. For instance, thin paper may be translucent, but thick paper, opaque. Ordinary gold is opaque, and yet very thin sheets of gold are transparent. Ordinary glass is transparent, but ground glass is translucent or even opaque. When light energy is absorbed by opaque bodies, it causes greater molecular vibration and becomes heat energy. When absorbed by the green chlorophyl of growing plants, however, it is changed to chemical energy and is the means of producing starch and sugar in plants.

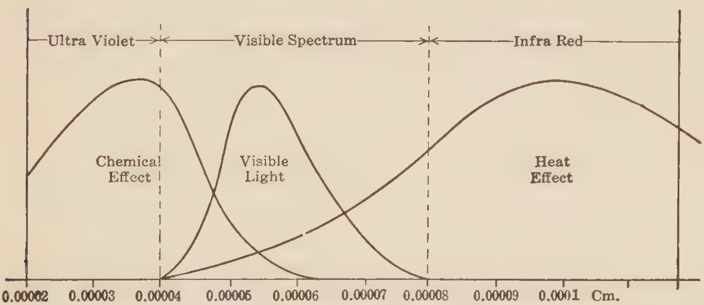


FIG. 160. — Distribution of chemical (ultra-violet), light and heat rays from the sun.

241. Radiant energy from the sun. The three most important radiation effects of the sun are the *chemical*, *light*, and *heat* effects. Figure 160 shows the distribution of these three forms of energy in average sunlight. We are

more or less familiar with the heat and light effects, and the chemical effects, though less understood, are just as impor-

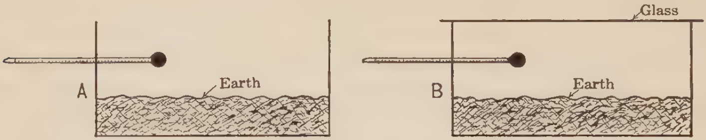


FIG. 161. — When two boxes of earth *A* and *B* are exposed to the sun's rays, *A* being open and *B* closed with glass, a thermometer will register a higher temperature in *B*. This is the principle underlying the use of the cold frame.

tant. You have observed that clothing, carpets, and wall-paper fade. Colored materials do not fade if ultraviolet light is excluded. Fading is due to chemical change brought

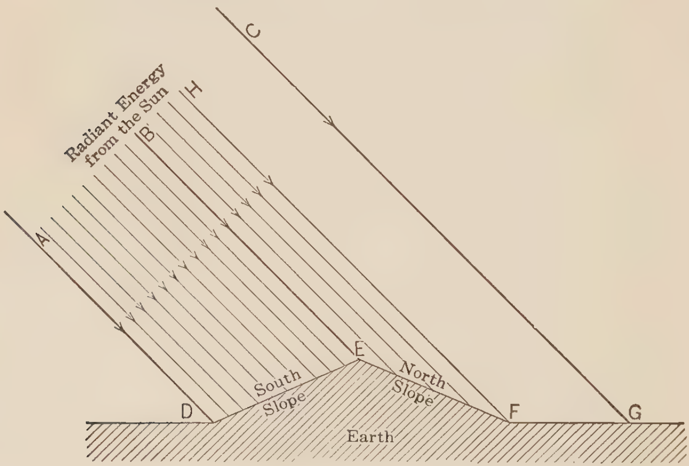


FIG. 162. — A southern slope of given area intercepts more of the sun's rays than a northern slope of the same area.

about by the so-called chemical rays. Artificial violet rays are used in chemical industries, as in the tanning of leather, in sterilizing water, and for certain health treatments.

Absorption of light energy by matter results in heat energy. The *cold frame* used by gardeners in early spring is, in reality, a kind of trap to "catch" heat. Radiant energy easily passes through the transparent glass and warms the soil, which in turn warms the air. The warm air cannot escape by convection or by wind action, as it does over the uncovered earth. The radiant heat from the earth passes through the glass less readily than the radiant light energy from the sun. This is an important factor in the value of the cold frame, because about half the energy radiated by the sun is the luminous, or light, energy. The temperature of the soil, both in and out of a cold frame, depends largely upon the angle at which the sun's rays strike the earth. It is common knowledge that a southern slope is warmer than a northern slope, and therefore more desirable for an early garden. In Fig. 162, *AB* and *BC* are equal beams of radiation from the sun. Study the diagram until you can explain it. The air absorbs a considerable part of the radiant energy which passes through it. We know that clouds shut off the light and heat of the sun. Experiments made by Langley show that the greater the depth of air through which radiation comes the less the radiant energy. His experiments were conducted at the base and summit of a mountain about 15,000 feet high, and the results are indicated graphically in Fig. 163. Both the total radiation and the proportion of ultraviolet light are greater at the summit than at the base of the mountain.

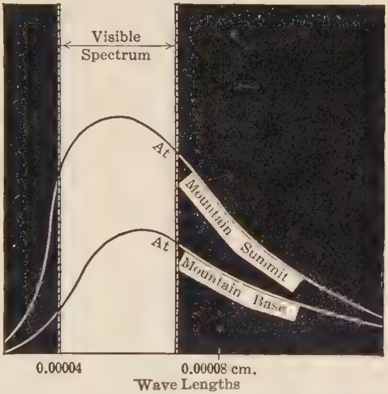


FIG. 163. — The intensity of the sun's rays is decreased by passing through a greater depth of air.

242. Shadows. You cannot see around a corner. This is because light travels in straight lines. One consequence of this property of light is the shadow. When light falls upon an opaque body, the space behind it is dark; this darkened space is the *shadow.* A shadow is not the surface in one plane which we often see upon the ground; it is the entire space (three dimensions) from which the light is cut off. The **umbra** is a shadow produced when all the light is cut off from a given space; the **penumbra** is a partial shadow produced when only a part of the light is obstructed. Eclipses of the sun and moon occur when the earth or the moon traverses the shadow which is cast by one of the bodies as it passes between the sun and the other body. In Fig. 164, an eclipse of the sun is shown. Where the umbra of the moon touches the earth, the sun is in total eclipse. Under the penumbra a partial eclipse will be observed.

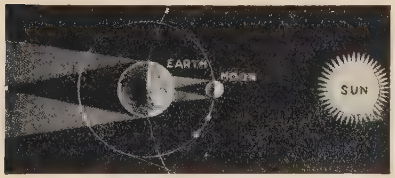


FIG. 164. — Total eclipse of sun.

243. Laws of reflection. If a plane mirror is held in a beam of light in a dark room, the beam will be reflected. A line perpendicular to the mirror at the point where a ray of light strikes it is called a **normal.** A single ray of light coming to the mirror is an **incident ray;** one coming from the mirror is a **reflected ray.** By turning the mirror back and forth, various angles will be made between the incident ray and the normal. These angles are **angles of incidence.** In each case it will be observed that the angle between the reflected ray and the

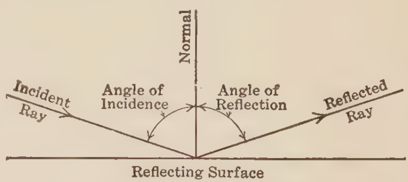
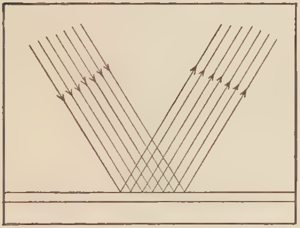


FIG. 165. — The angle of incidence equals the angle of reflection.

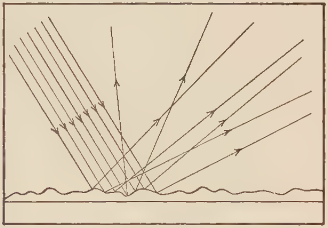
normal is equal to the angle of incidence. The angle between the reflected ray and the normal is known as the **angle of reflection.** The relation of these angles is stated in the law of reflection:

The angle of reflection is always equal to the angle of incidence.

244. Diffuse reflection. If a mirror reflects a strong beam of light to the eye, it produces a blinding glare, but if a piece of soft, white cloth replaces the mirror, the glare is removed. There is no well-defined beam of light reflected from the cloth, but instead, a much larger space is lighted to a lesser intensity. This scattering of light is called **diffusion.** The



Reflection from a smooth surface



Reflection from a rough surface

FIG. 166. — A rough surface scatters the rays of light causing *diffusion.*

explanation of diffusion of reflected light is readily understood from a study of two diagrams showing light reflected by a smooth and a rough surface. *Diffuse reflection* is produced by plaster, blotting paper, " flat " paints, and rough surfaces in general. Diffusion of transmitted light is also caused by a rough surface, such as ground glass, and by substances which interfere with the direct transmission of light, as opal or milk glass.

245. Spread and mixed reflections. Some surfaces, for example, one coated with aluminum paint, spread the light to a small extent, but the general direction is that of the regular reflection; this is called *spread reflection. Mixed reflection* is a combination of regular and diffuse reflection.

This results when light is reflected from a glazed or varnished diffusing surface. Figure 167 shows how these four types of reflection differ.

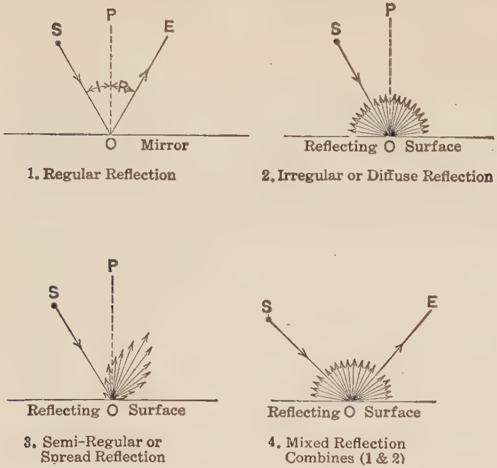


Fig. 167. — Types of reflection.

246. Images in a mirror. When you stand in front of a mirror, you appear to see yourself behind it. As you approach the mirror, your image approaches. If you step back, your image moves back. The explanation of the image and its

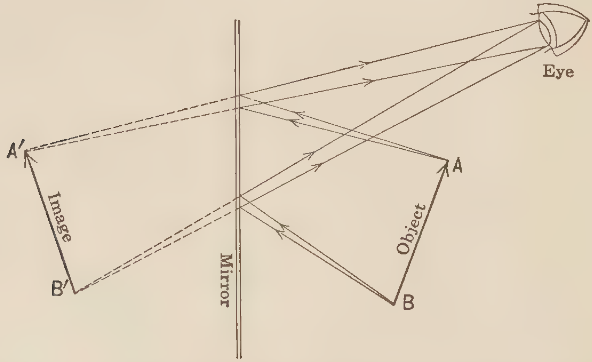


Fig. 168. — The mirror changes the direction of the rays of light so that the object AB appears to be at $A'B'$.

position behind the mirror is simple. Diverging rays of light from each point on the object are reflected by the

mirror to the eye. Objects appear to be in the direction in which light comes to the eye. The object one sees by means of the mirror is not in the direction in which the light comes; hence, what is seen is termed the **image.** The distance between the image and the eye is judged by the angle made by the diverging rays which enter the eye. They appear to meet at a distance back of the mirror equal to the distance of the object in front of the mirror. The image is unreal, or *virtual;* that is, if the eye is not looking into the mirror there is no image back of it. Experiments show that the image and object are equidistant from the mirror and are of the same size, but that the image is reversed.

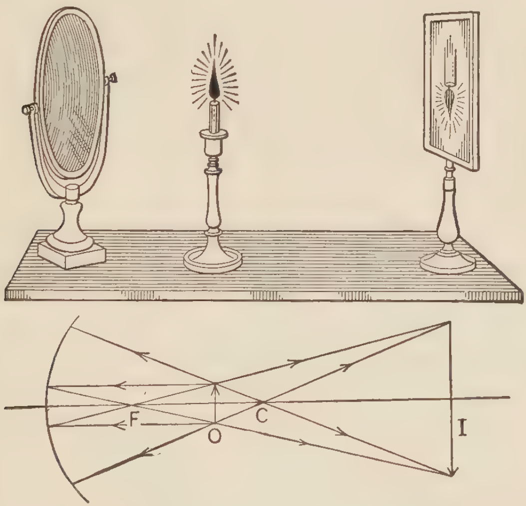


FIG. 169. — How a convex mirror produces an image.

247. Concave mirrors. Rays of light parallel to the perpendicular axis (the line connecting the center of the mirror with the center of curvature), when reflected by a concave mirror, meet at a point on the principal axis, called the **principal focus.** If the source of light is nearer, so that the

rays are diverging, rays from any point on the object will focus farther from the mirror. An image is produced where the rays are brought to a focus. The chief use of such mirrors is to reflect light in useful directions. If a source of light is placed at the principal focus, the light which strikes the mirror will be sent back in a beam of parallel rays. This gives an intense beam of light that will reach for a long distance. The **parabolic mirror** is much used in small searchlights and automobile headlights. By placing the light a little nearer the reflector than the principal focus, the beam of reflected light will be spread slightly. Searchlights throw a powerful beam of light, visible a hundred miles away.

248. Refraction. When light goes from one medium to another medium of different density, its speed is changed. All transparent bodies decrease the speed of light slightly; the denser the body the greater its effect. When a beam of light goes from air to water, it must enter the water either perpendicularly to the surface or obliquely. If it enters perpendicularly, the entire wave front enters the denser medium at the same instant, and all of it is slowed up. In this case there is no bending, but the beam continues on through the water in the same straight line. If the beam is oblique to the surface, some rays will enter the water while others are still in the air. The result of this will be apparent by a study of Fig. 171. *ABCD* are different rays in a beam of light passing from air to glass. The line *ad* is a wave front. Consult Fig.

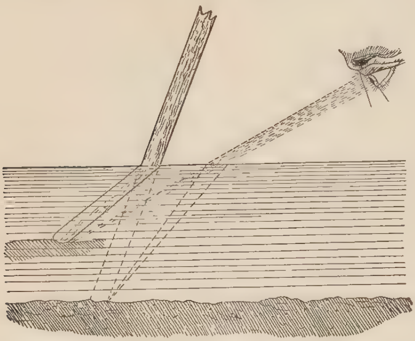


Fig. 170. — How refraction changes the apparent position of objects seen in water.

171, part 2, and apply the following explanation: When B travels from b^1 to b^2, a has traveled from a^1 to a^2. When D has traveled from d^1 to d^4, A has traveled from a^1 to a^4. Since a^1a^4 is shorter than d^1d^4, the wave front, a^4d^4, in glass cannot be parallel to the wave front in air. Not only is the direction of the beam changed in the glass, but the beam is wider than in the air. The bending of light rays on entering a medium of different density is called **refraction.** It is due to refraction that objects standing partly in water often appear bent or broken, and the depth of a stream appears less than it really is.

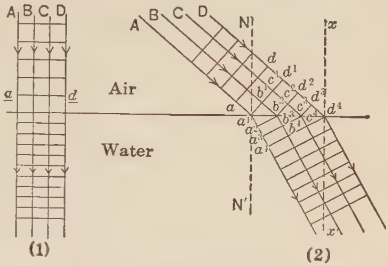


FIG. 171. — Refraction of a beam of light in passing obliquely from one medium into another of different density.

249. Law of refraction. By reference to the diagram explained in the previous paragraph, it will be seen that in passing from air to water light is bent *towards the normals* NN' and xx'. If, however, it passes to the air, it is bent *away from the normal.* The **law of refraction** is stated thus:

When a ray of light passes from a rarer to a denser medium, it is bent towards the normal; when it passes from a denser to a rarer medium, it is bent away from the normal.

250. Lenses. Common lenses are either **convex** or **concave.** Their surfaces are portions of spheres. The center of the sphere of which each surface is a part is the **center of curvature.** The center of a lens having two curved surfaces is called the **optical center.** The center of the curved surface of other lenses is the optical center. A line passing through the center of curvature and the optical center is the **principal axis.** When rays of light parallel to the principal axis enter a double-convex lens, they are refracted and cross

each other on the other side of the lens in a point which is called the **principal focus.** The principal focus nearly coincides with the center of curvature. The distance from the principal focus to the optical center is the **focal length** of the lens. This may be determined by holding the lens in

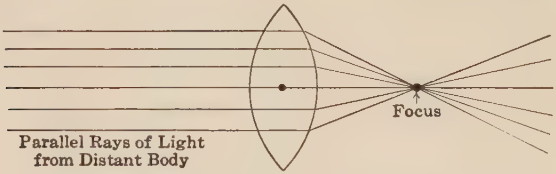


FIG. 172. — Focus of parallel rays by a convex lens.

the sunlight and moving a paper screen behind the lens until the brightest image is produced. The heat concentrated on one spot in this way will sometimes set fire to paper; hence the lens is often called a "burning glass."

251. Images in lenses. When a convex lens is held between a screen and a bright light in a darkened room, and moved toward the screen or toward the light, some point will be found where a clear image of the light will be produced

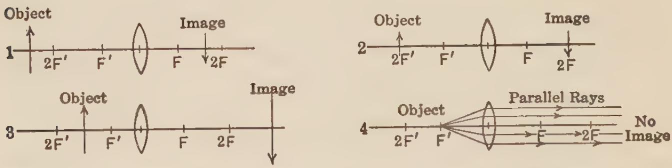


FIG. 173. — Relation of image to object under varying distance of object from lens.

on the screen. This is a real image, because it is there whether you are looking at it or not. The rays of light, after passing through the lens, are focused on the screen. The image of an object is produced where light from the object is brought to a focus. The relation of the size and position of an image to the object is indicated in Fig. 173.

252. Construction of images. When the image of an object is produced by a lens, the image of any point on the object may be located by tracing two of the rays of light. Draw a line from the point to the lens, parallel to the prin-

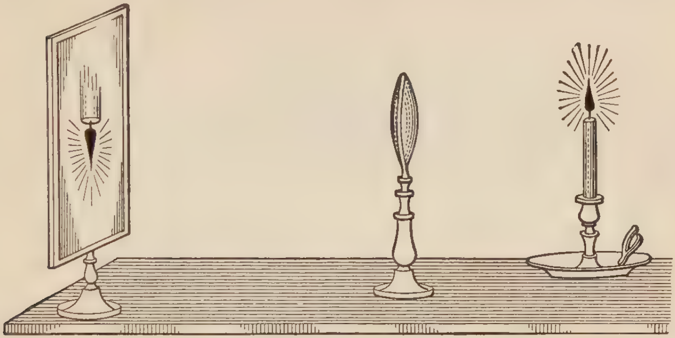


Fig. 174. — A convex lens produces a real image but inverted; it may be larger or smaller than the object.

cipal axis. This will pass through the principal focus on the opposite side of the lens in convex lenses, and in the case of concave lenses it will bend away from the principal axis at such an angle that, if it were prolonged, it would pass through the principal focus on the same side of the lens as

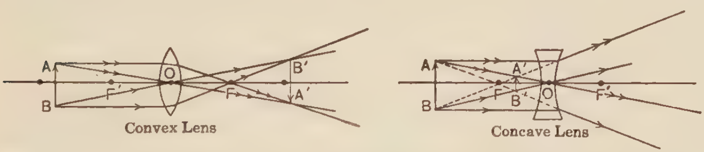


Fig. 175. — Construction lines needed in locating images of objects through lenses.

the object. Draw a second line from the point through the optical center. This ray is not refracted but continues on unbent. The point where these two lines cross each other is the focus of all rays of light passing from the point on the object to the lens, and hence it marks the position of the

image of the point. The images of other points on the object are determined in a similar way, and thus the image of the object is located.

253. Intensity of illumination. It is a matter of everyday experience that the nearer we hold our book to the light the more intensely it is illuminated, and yet few people can tell you how much more brilliantly it is lighted when it is moved one, two, or more feet nearer to the light.

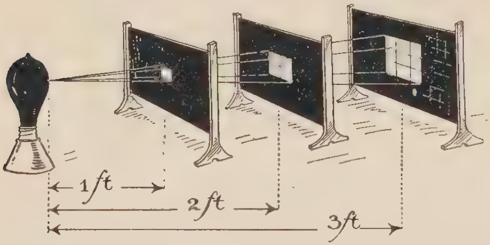


FIG. 176. — The intensity of illumination at 3 ft. is only $\frac{1}{9}$ of that at 1 ft. from the light source.

In a dark room, cover a lamp with a metal chimney which has a pin-hole on one side. At a distance of 1 foot, place a screen of cardboard having a hole 1 inch square in it. The light coming through this 1-square-inch area will light an area of 4 square inches on a screen 2 feet from the light. Evidently the same quantity of light falls on the 1-square-inch area at 1 foot distance as would fall on a 4-square-inch surface at 2 feet distance. Hence each square inch at 2 feet receives one-fourth the light that a square inch receives at 1 foot distance. If we move the second screen to a place 3 feet from the light, 9 square inches will be lighted, and the intensity of light will be one-ninth of that at 1 foot. This is stated in the **law of inverse squares:**

Other conditions being the same, the intensity of illumination upon any surface varies inversely as the square of its distance from the light.

The intensity of illumination at any distance varies directly with the intensity of the light source. The intensity of illumination also depends upon the angle between the

surface and the rays of light. The greatest intensity is found when the surface is at right angles to the rays of light. *AB*, *AC* and *AD*, Fig. 177, are all equal surfaces, but *AD* receives only about half the light that *AB* receives. This is the same principle that is involved in explaining why the slanting rays of the sun give us less heat and light than the vertical rays, even in spite of the fact that the sun is several millions of miles nearer to us at the beginning of winter.

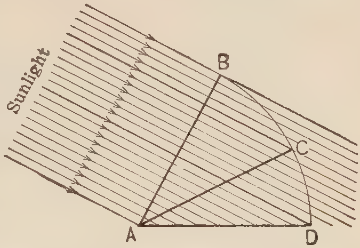


FIG. 177. — The intensity of illumination depends upon angle at which a surface meets the rays of light.

SUMMARY

1. Light is due to waves in the ether, which give us the sensation of sight.

2. Other ether waves, which differ from light waves only in their frequency of vibration, are those of electricity, heat, ultraviolet light, and the X-ray.

3. A light wave travels outward in a hollow sphere. A radius of the sphere represents a ray of light. Light may be reflected, absorbed, or transmitted. Bodies are opaque, transparent, or translucent, depending upon their ability, respectively, to obstruct the passage of light, to transmit it freely, or to transmit and at the same time diffuse it.

4. All ether waves are forms of radiant energy. The important forms of radiant energy from the sun are ultraviolet rays, light, and heat. When radiant energy is absorbed by matter, it is changed to heat. Radiant energy of the sun is absorbed to a considerable extent by the air. It is more intense at high altitudes than at low altitudes, for this reason.

5. Light travels in a straight line. A shadow is the space from which light is obstructed by an opaque body. Eclipses occur because of the passage of one heavenly body into the shadow of another.

6. A plane mirror reflects light in such a way as to make equal angles on either side of a perpendicular at the point of incidence.

7. Uneven surfaces and translucent bodies scatter or diffuse the light.

8. An image is as far behind a plane mirror as the object is in front of it.

9. A concave mirror focuses the light upon one point, except when the source is at the principal focus. Then it sends off a beam of parallel rays. Concave mirrors of the parabolic type are much used in automobile headlights.

10. All light passing into a denser or a less dense medium, at any angle except a right angle, is bent from its original direction. This bending is called refraction. When passing to a denser medium, light bends towards the normal; when passing to a less dense medium, it bends away from the normal.

11. Because of refraction, light, in passing through a lens, is focused so as to produce images in various places, depending upon the position of the object giving out the light. Light from distant bodies comes in practically parallel rays, which are brought to a point at the principal focus by a convex lens. The distance from the principle focus to the center of the lens is the focal length of the lens.

12. Intensity of illumination varies inversely with the square of the distance. It varies directly with the intensity of the light source.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. Images in mirrors and in lenses.
2. Apparent displacement of bodies through refraction.

3. Study the reflection, refraction, and diffusion of light with the optical disk.
4. Determine by experiment the relation of intensity of illumination to distance.

REFERENCE BOOKS

Butler. *Household Physics.* Whitcomb and Barrows.
Good. *Laboratory Projects in Physics.* The Macmillan Company.
Smith. *Elements of Applied Physics.* McGraw-Hill Book Company.

CHAPTER XVI

NATURAL LIGHT

254. Sources of natural light. There are many reasons why sunlight is so important to us: it makes objects visible;

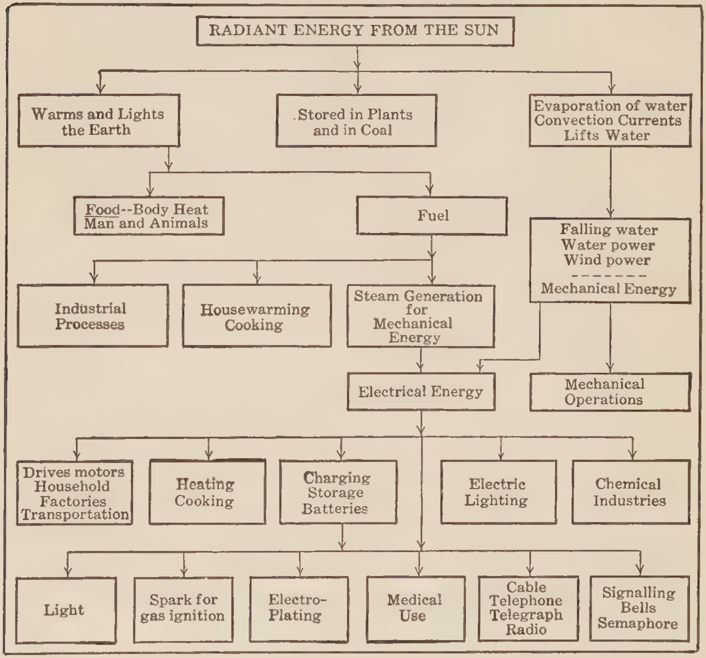


FIG. 178. — Every form of energy we use can be traced back to the sun.

it produces heat; it brings good cheer. Light is a germicide and promotes good health. Its use makes photography possible. Our food is derived directly or indirectly from plants, which cannot grow in darkness.

Except for such trivial amounts of light as come from stars, from the Northern Lights, from phosphorescent light produced by animals, and the like, our natural light comes from the sun. The sun is, as well, the great source of the earth's energy, which we find stored in coal, in running water, and in moving air, or the wind. Our own energy for work may be traced back to the sun. The sun is some 93,000,000 miles away, and yet its energy, in the form of heat and light, traverses this distance in the short space of eight minutes and comes to us at a speed of 186,000 miles per second.

255. Natural light in the home. All sides of the house do not receive equal amounts of light. North windows receive direct sunlight only in the early morning and late afternoon in summer, and not at all in winter. Practically all light coming to north windows is from the sky, which gives a subdued sunlight reflected and diffused by the particles of dust and moisture in the air, and by the air itself.

The usual practice of allowing window space to equal one-quarter of the floor space for most rooms, and one-sixth of the floor space for sleeping rooms, may or may not be satisfactory. There are frequently obstructions to sunlight and sky light, which may seriously interfere with efficient lighting. In planning the window space, one should consider the obstruction of light by high ground or cliffs, tall buildings close by, trees now present or likely to grow, and piazza or porch roof. On the east and west sides of the house, which are without sunlight for a portion of each day, as well as on the north, the amount of sky visible from the windows is important, for when these windows do not receive direct sunlight, the rooms must be lighted by sky light. If there is too much light, it must be regulated by controlling devices, such as awnings, blinds, shades, curtains, or draperies.

A study of light intensities out-of-doors, with a bright sun, was made by the Edison Lamp Engineers. The results of

their tests are shown graphically in Figs. 179 and 180. The **foot-candle,** used to indicate the light intensity in these diagrams, is the amount of light 1 candle will give at a distance of 1 foot.

FIG. 179. — Out-of-doors illumination in the bright sun may be as high as 8000 foot-candles.

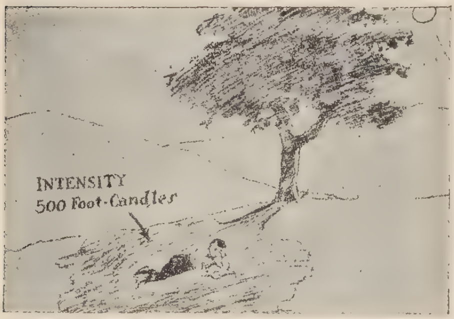


FIG. 180. — When some object obstructs the direct rays of the sun, the intensity of illumination is greatly reduced.

256. Facing the sunlight. Some architects tell us that there is a great advantage in having a house so placed that its diagonals, corner to corner, rather than its walls, are in a north-south and east-west line; and that, if we wish all the sunlight that we can get into our house, towns should be planned with streets running N. E.–S. W. and N. W.–S. E. If we consider a square house with corner rooms and with windows on two sides of each room, the sunlight received in the spring and fall is the same, whether the house be placed one way or the other. In winter the house with north-south diagonal receives less, and in the summer more sun-

shine than when the wall is in a north-south line. This can hardly be called an advantage. There is, however, a slight advantage for the north-south diagonal in that the light is more evenly distributed throughout the different rooms. To get the most benefit from the sunshine in the house, it is of more importance to plan the arrangement of

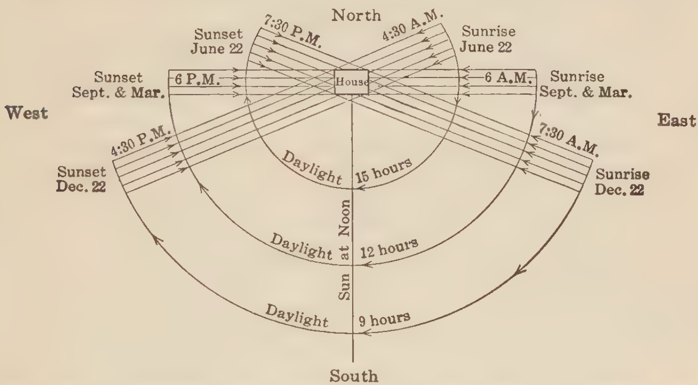


FIG. 181. — Direction and duration of sunlight for the different seasons. How many hours will a December sun shine into an east window?

the rooms than to plan the orientation of the house. Little used rooms and hallways, when possible, should be placed on the north.

257. Sky light. Sunlight is diffused by the air through which it passes, so that we receive light from all parts of the sky. Were this not true, our north windows, except for three hours a day in midsummer, would receive no more light in the daytime than they do at night. Because of this valuable source of light, it is important to consider the sky angle (arc of the sky) which is visible through the window from remote parts of the room. The brilliancy of the sun is some 200,000 times that of the sky, and yet this rather feeble sky light is of inestimable importance to us. The visible sky angle should be at least 5 degrees at any part of

the room where work is being done which requires as much light as reading. Hills, trees, shrubs, and buildings frequently obstruct light and decrease the visible arc of the sky. Such obstructions are particularly bad if on the north, where practically all light must come from the sky.

258. Sky light in apartments. Country and suburban houses may easily secure good natural light, but the city apartment is usually less favorably situated. As a rule, windows are on the front and back of the house. Little, if any, direct sunlight is available, and even the arc of the sky, which can throw its diffused sunlight into the windows, is frequently inadequate to make good lighting conditions. Particularly is this true for the lower floors. Consider a four-floor apartment which is facing a five-floor apartment across a narrow street, or which backs up against it across a narrow alley in the rear. By consulting the diagram, it will be seen that the sky angle for the window on the fourth floor is widest. The sky angle decreases for windows on lower floors (see angles b and c), and no direct sky light at all enters rooms on the first floor. Moreover, as the angle of incidence increases, the amount of light transmitted by

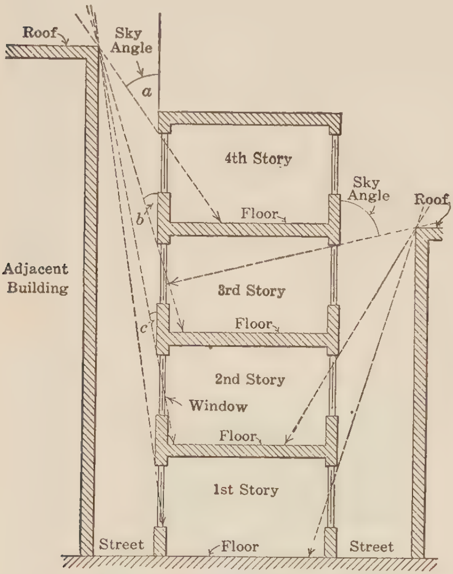


FIG. 182. — The amount of light in an apartment house frequently depends upon the nearness of adjacent buildings.

ordinary window glass is diminished. The amount of light transmitted at various angles is shown in Fig. 183.

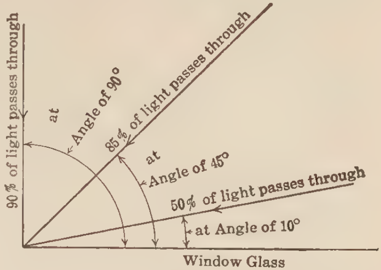


Fig. 183. — The greater the angle between the incident ray and the glass the greater the amount of light transmitted.

The light in these lower rooms may be increased many times by using, in the upper sash, *factory ribbed glass* with about twenty-one ribs to the inch, or by the use of *prism glass*. In rooms on light-shafts, prism glass will often increase the amount of light fifteen or more times. The prismatic glass is more efficient than the ribbed, but it is also more expensive. It is important to select prismatic glass with the proper angle of prism to meet the needs of a given room. After refraction, the light is reflected by the lower surface of

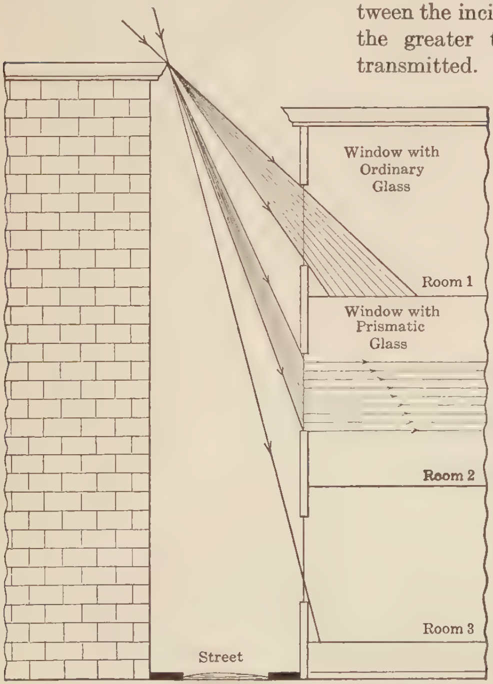


Fig. 184. — Prismatic glass makes it possible to bring natural light to the rear of some rooms which would be very dark with ordinary window glass. — See room 2 above.

the prism. The reflected ray will be refracted again as it enters the room, unless it be a horizontal ray. Study the diagram shown in Fig. 185. The direction of the light from the sky to different windows varies, and without proper prism angles the light received by the glass might be reflected to the ceiling, rather than to the back of the room.

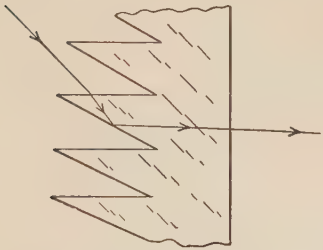


Fig. 185. — How prismatic glass changes the direction of a ray of light.

The reflection of light from opposite buildings is an important factor in lighting lower floors. Light-colored buildings are much better reflectors and so give better lighting. Lower floors frequently receive considerable reflected daylight, when no direct sky light is received.

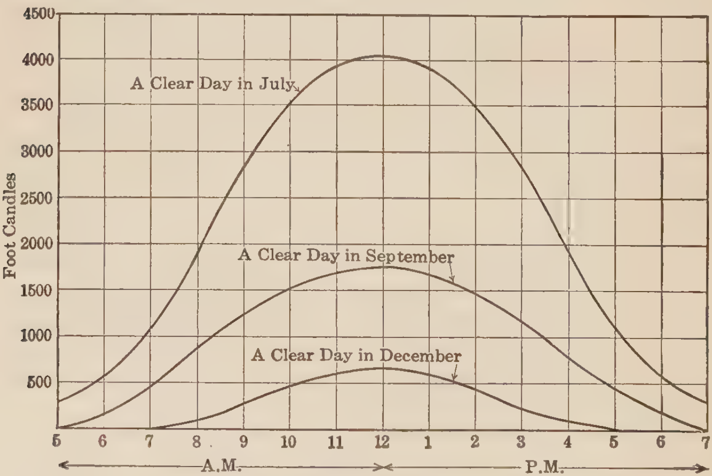


Fig. 186. — A comparison of daylight intensities at different seasons.

259. The daylight efficiency of the house. In order to measure the daylight efficiency of your house for any par-

ticular place where you are using daylight, it is only necessary to measure the illumination at that point, and to compare it with the illumination in a free space out-of-doors. The ratio of illumination at one point within the house to the illumination out-of-doors is the **daylight factor,** or **daylight efficiency,** of a building. This runs from a fraction of one per cent to several per cent. If you know what intensity of light is required for a particular piece of work, the daylight factor, and the intensity of outdoor light for the particular time in question, you can then find out how much, if any, artificial light should be used. This will also indicate how efficient the house is with respect to natural light for that particular piece of work. Variations come at different times of day, with different seasons, and with different weather conditions, as is shown by the accompanying chart in Fig. 186.

260. Glass used in the house. It is sometimes desirable to subdue direct light, or to pass some light through glass without making objects on the other side visible. This may be accomplished by various methods of surface treatment. The surface may be chipped, ribbed, ground by sand blast, or etched. Some colored glass permits a person on the dimly lighted side to see persons on the brightly lighted side, to whom the glass appears opaque. Many of these translucent forms of glass, and opal glass as well, diffuse light and for this reason are also used as shades for artificial lights.

Window glass is made in single and double thicknesses by blowing huge cylinders which are later cut and flattened in furnaces. All plain glass has a somewhat wavy surface, which can always be recognized when light is reflected from it at certain angles. Plate glass, the surfaces of which are smooth and even, never shows a wavy surface. Double-thickness glass sometimes has woven wire cast in it. This is used as a fireguard, since glass cracked by the heat will be held in place by the wire.

261. Sunlight colors. The sunset red and the noonday blue, all the varied hues of the rainbow, the dull gray of a rainy day, and the brilliant white light are all sunlight. If a glass prism is placed in the path of a beam of light which enters a darkened room, it will throw a band of colors, called the **solar spectrum,** on the wall. White light, then, is a mixture of all these colors. We have already learned that light consists of ether waves of various lengths, which distinguishes it from other radiant energy in the ether. Now we learn that light waves consist of many waves of different lengths. Waves of one particular length give one color sensation; waves of another length give a different color. Red, green, and blue differ merely in their vibration frequency and wave length. Red at one end of the spectrum has the longest wave length of light rays. Violet at the other end of the spectrum has the shortest wave length. All other colors have wave lengths somewhere between these two. The wave lengths and vibration rates of the six principal colors of the solar spectrum are indicated in Table XVII.

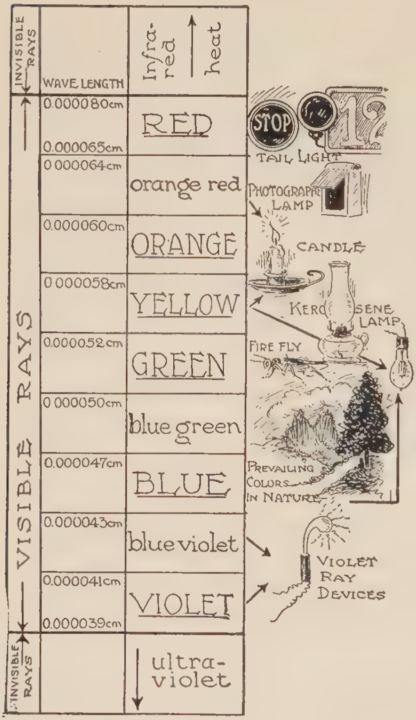


FIG. 187. — Distribution of light waves.

TABLE XVII

WAVE LENGTHS AND VIBRATION RATES OF COLORS IN THE SOLAR SPECTRUM

	Length of waves in millimeters	Number of vibrations per second
Red	0.000760	395,000,000,000,000
Orange	0.000656	458,000,000,000,000
Yellow	0.000589	510,000,000,000,000
Green	0.000527	570,000,000,000,000
Blue	0.000486	618,000,000,000,000
Violet	0.000397	760,000,000,000,000

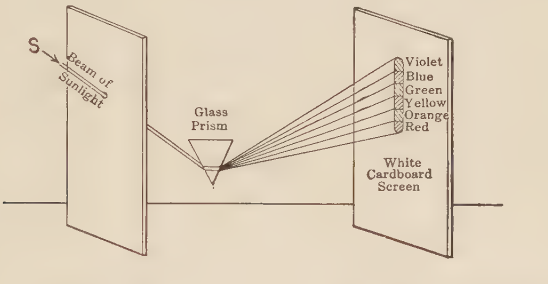


FIG. 188. — The solar spectrum.

262. Colored bodies. Objects that have the property of absorbing light waves of all lengths are *black*. Objects that have the power of reflecting light waves of all lengths are *white*. A red body is one that absorbs all the light waves except those producing the sensation of red. A blue body reflects wave lengths of blue and absorbs all others. Pieces of the same cloth may be dyed different colors, because each of the different dyes has the power to reflect light of different wave lengths. Colored glass in white light transmits only the color due to the wave lengths that are not absorbed. A person wearing a blue dress enters a room whose windows transmit only red light, and the dress appears black. Why? What change would result in the appearance of a white collar? A "white" collar is one that in ordinary light reflects all wave lengths; but if it receives only the red

waves, it can reflect only red waves and therefore it appears red.

263. Color nomenclature. We find few pure colors in things about us; instead, there are mixtures of two or more pure colors. The dominant spectrum color in these mixtures is called **hue.** For example, the eighteen outer circles in the chart shown in the frontispiece — *y*, *g–y*, *y–g*, *g*, *b–g*, etc. — are hues. Hues which lie opposite each other in this chart are *complementary*, and will, if mixed in equal amounts, neutralize each other and yield *neutral gray*, shown in the large central circle. The *intensity* (brilliancy, or chroma) of any hue may be dulled or softened by mixing a little of its complement with it. The *value* of a color is changed by mixing white or black with it, thus modifying its tone. A number of these tones in sequence form a scale of color. If white is mixed with a color, a *tint* results; but if black is mixed with the same color, a *shade* is produced. The hues from yellow through green and blue to the violet, including the various tints shown in the right-hand half of the diagram, are called *cool colors*, the shades and the hues from violet through red and orange to the yellow, shown in the left-hand half, are *warm colors*.

264. Color charts. Refer again to the color circle in the frontispiece. When each spectrum color is modified by an adjacent color, the resulting hue is designated in such a way as to indicate the predominating color and the modifying color as well. For example, the mixture of a little green with blue gives *green-blue*, but the mixture of a little blue with green gives *blue-green*. The six spectrum colors and the two hues of each are represented on the outer circle. The neutral gray in the large circle in the center is produced by mixing any two opposite (complementary) colors or by mixing all the colors. Each of the colors in the six large circles surrounding the central circle results from modifying the active color near it with a little of its complement. The best harmony of colors results from combining modified

complementary colors. The color chart below the color circle shows the result of modifying all the hues, first, with white, yielding tints, and second, with black, producing shades. Only two tints are suggested in the chart, but the number may be increased indefinitely. So also between the active color and black there may be many shades instead of the two illustrated in the chart.

265. Harmonious colors. Just as, in music, certain notes when sounded at the same time are harmonious, so, in light, certain color combinations appear harmonious to the trained eye. At the same time, certain other combinations of color are just as offensive to one who has been trained to know good color combinations as a discord of sounds. As one can be trained to appreciate harmonious sounds, so one can learn to recognize certain combinations of color which are harmonious. Complementary colors may always be used together, but the effect is more pleasing when the intensity of each pure color is modified by a bit of its complement. In nature, colors are as a rule modified, sometimes by mixture with other colors, sometimes by the atmosphere and sometimes by reflection or from contrast with colors of near-by objects. In color arrangement these possibilities must be considered. Whenever a pure color is found in nature, it is small in extent compared with the dull or gray area. So in our use of colors, it is well to remember that a small spot of intense color will balance a large area of neutral color. The best color harmonies come from closely related hues, as yellow and orange, or from widely separated (complementary) hues, as yellow and violet, or red and green. When two colors near each other in the spectrum are used together, the effect is better if each one of them is modified by the addition of a little of the other, so that both of them, while having distinctly different hues, have a color in common. The color of the walls of a room may harmonize with the woodwork either by similarity or by contrast. Any color appears brighter against a black background and darker when it

has a white background. Complementary colors give the strongest contrasts.

266. Color mixing. A mixture of all the colors coming from the sun gives white light. Make a blue spot on white paper, and an orange spot a few inches from it, and then view the two colors by means of a glass plate held vertically between them, so that one spot seen by reflection overlaps the other seen through the glass. White light results. Any two colors which, when mixed, give a sensation of white or gray are complementary colors. Mixing pigments, as paints and dyes, is quite a different matter from mixing colors (sensations). The physicist and the psychologist mix orange and blue colors, and white results. The artisan and the artist mix blue and yellow pigments, and green results. If a mark is made on the blackboard with blue crayon and a band of yellow is made over it, the result will appear green. A yellow pigment absorbs all spectrum colors except yellow and green, while blue pigments absorb all but blue and green. Green is the only color reflected by both pigments and is therefore the only color seen when the two are mixed.

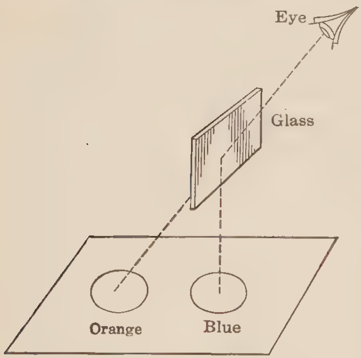


FIG. 189. — Complementary colors blue and orange give white.

267. Three-color printing. Color printing depends upon color mixing. Three colored inks, yellow, red and blue are used. By the right mixture of these three pigments, any desired color can be produced. These three colors, because they may be used to produce all other colors are regarded as the **three primary pigments.** The plates for printing each of these inks are made from photographs of the object taken

through color filters. The color filter for each plate and the ink to be used on the plate are complementary colors. The print is made on white paper. First, the yellow is printed, then the red, and finally the blue is printed over the others. Certain parts of the picture will receive only one color, other parts will receive a mixture of two colors and still other parts may receive all three. The proportion of the colors mixed must vary to produce colors different from those of the three inks. When skill and good judgment are used in selecting both color filters and inks, the colors of the original object photographed will be reproduced with great exactness.

268. Reflection of light by fabrics. Smooth, shiny fibers, like those of silk and mercerized cotton, reflect light without much diffusion, while cotton, which has a flattened fiber, gives a highly diffused reflection. Wool diffuses light as does mohair, but the mohair fiber has the scales closer together than the wool and as a result it is more lustrous. Not only the material but also the texture affects reflection. A smooth surface gives greater surface reflection of white light, while a rough surface, which reflects light that has penetrated the material, gives less white but more of the true color of the material. The reflection of white light from materials with high luster dilutes the colored rays. Wool and silk show greater differences in appearance from this cause than cotton, and for this reason colored cottons are easier to match. Silk velvets, however, show the least difference in appearance. This is because light penetrates deep into the fibers before it finds a surface suitable for reflection. Some materials are iridescent, displaying a variety of changing colors, much as does a very thin film of oil or tar on water, or the thin wall of a soap bubble. Reflection of light from two surfaces, one of which is slightly below the other, causes diffused waves, which in places interfere with each other and so destroy the effect of the wave, while in other places they reinforce each other and thus intensify the color.

269. The rainbow. The rainbow is the result of a natural separation of sunlight into its elements, by the unequal bending of light waves of different lengths as they pass through drops of rain. The red rays are separated from the others and grouped together. In a similar way the orange, the yellow, the green, the blue, and the violet are each separated into a group by themselves. The separation of sunlight into colors by drops of water is accomplished in accordance with the same principle that underlies the separation of sunlight by a glass prism. The series of colors produced is the solar spectrum, which has already been described.

SUMMARY

1. Houses should be so planned as to secure the most sunlight in the rooms that are most used. Regulation of natural light in the house is of much importance.

2. Sky light, or diffused sunlight, gives us a more even distribution of light and, for the greater part of the time, is the only light that enters our north windows.

3. The greatest poverty of natural light is found in the lower stories of tall apartment houses separated by narrow streets. Prismatic glass in the windows will help to increase the amount of light received.

4. Glass may be made so that it will diffuse light and allow light to pass through, without making people or objects on the other side visible.

5. All sunlight is a mixture of light of many wave lengths. The mixture is white light, but the light resulting from any one wave length is color. The glass prism separates sunlight into a series of colors, called the solar spectrum. Red has the longest waves and violet the shortest.

6. Smooth fibers, like those of silk, and smooth surfaces of cloth reflect light without diffusion, giving a white light which dilutes the real color. Flat fibers, like those of cotton, diffuse the light. Rough surfaces allow the light to

penetrate, with the result that, when it is reflected, it discloses more of the true color of the cloth.

7. The color of a body depends upon the length of the light waves that are reflected by it.

8. Complementary colors are those which, when mixed, produce white or gray.

9. Red, yellow, and blue when mixed give white. From these three colors all other colors may be produced. They are therefore regarded as primary colors or primary pigments.

10. Certain color combinations are harmonious, while others produce color discords. The best color harmony results from the use of neutral colors either closely related or widely separated in the color spectrum.

11. The dominant spectrum and color of any material is its hue. The different values that result from mixing white or black with a color are called tones. When a color is mixed with white the tones are called tints, and when mixed with black they are called shades.

12. The rainbow results from the separation of sunlight into colors by refraction and reflection.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. Daylight in my house.
2. Rainbows.
3. Mirage.
4. Color harmonies in the home.
5. Test color-mixing: with the color wheel; with pigments.

REFERENCE BOOKS

FREDERICK. *Household Engineering.* (Pages 452–5.) American School of Home Economics.

HUMPHREYS. *Atmospheric Phenomena.* In General Science Quarterly, January, 1921.

SARGENT. *The Enjoyment and Use of Color.* Charles Scribner's Sons.

SMITH. *Elements of Applied Physics.* McGraw-Hill Book Company.

CHAPTER XVII

ARTIFICIAL LIGHTING

270. Development of artificial lighting. The earliest account of man's using artificial light is that of his burning wood and using the pitch knot for a torch, some six thousand years ago. Following this, resins and pitch were extracted from wood and used. Many years before Christ,

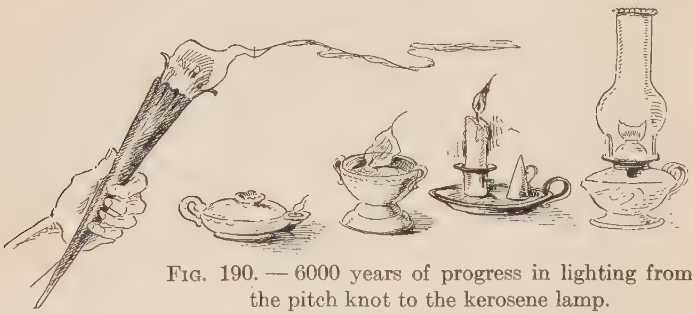


FIG. 190. — 6000 years of progress in lighting from the pitch knot to the kerosene lamp.

vegetable and animal oils were used. Tapers and lamps with wicks date as far back as the building of the Pyramids, and there was no important advance in the manufacture of these lamps until the nineteenth century. Candles were made two or three thousand years ago, and were in common use all through the Middle Ages. As late as 1834, the English House of Commons was lighted by candles. In this country, sperm oil and candles were the chief sources of artificial light, up to the time of the Civil War. Petroleum was discovered in Pennsylvania just before this, and it rapidly displaced the whale oil, which, owing to the scarcity of whales, had increased in price from 80 cents to $1.77 a gallon, while kerosene was soon reduced in cost to 55 cents a gallon. A

candle costing $2\frac{1}{2}$ cents would burn for seven hours. It is an interesting fact in the history of lighting that Cicero and Lincoln were dependent upon practically the same means of artificial light, no important improvement in methods of lighting having been made in all the intervening time.

By 1875, kerosene lamps had been improved to such an extent that tallow candles ceased to be important sources of light. Gas was used to some extent in cities and cost $2.50 per 1000 cubic feet. By 1895, kerosene oil had dropped to $13\frac{1}{2}$ cents a gallon and gas to $1.50 a thousand. Just before this, the first important improvement in the use of

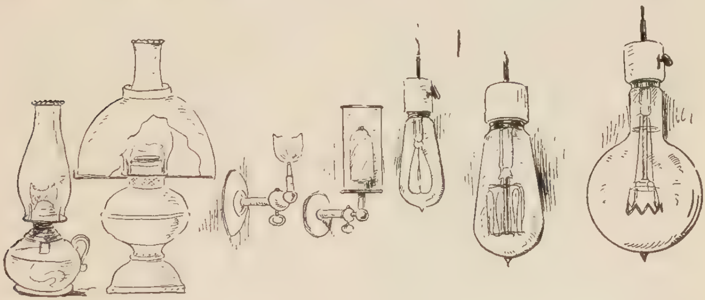


FIG. 191. — 50 years of progress in lighting from the kerosene lamp to the gas mantle and tungsten lamps.

oil lamps was made: the flat wick was replaced by a round wick with a central draft. The glass chimney was also in use at this period. At this time electricity and the Welsbach gas light were the chief light sources for cities. Mantles have since been greatly improved, and the use of tungsten in the incandescent electric lamp has greatly increased its efficiency. The amount of light used by the average thrifty family today is nearly forty times that used one hundred years ago, and yet it costs only two-thirds as much.

271. Sources of artificial light. The chief sources of light now used in the home are paraffin candles, kerosene lamps, gas lights and incandescent electric lamps. The gas

used may be ordinary illuminating gas, naphtha gas, or acetylene. In all these sources, the light-giving element is an incandescent solid. The fuel, in the case of candles, kerosene lamps, and gas lights, is, in every instance, rich in carbon. During burning, the carbon passes through a stage

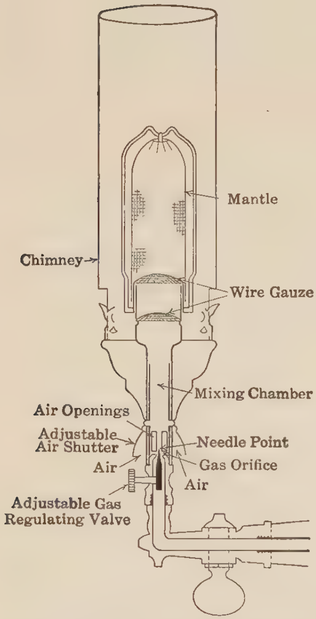


FIG. 192. — Upright gas mantle and burner.

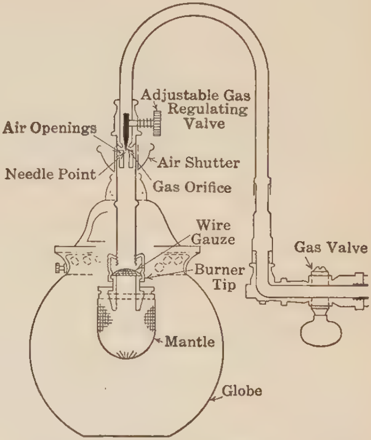


FIG. 193. — Inverted mantle burner.

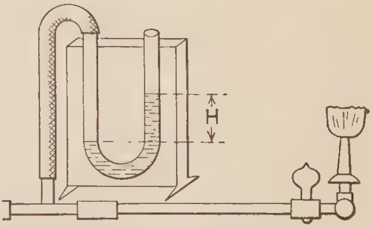


FIG. 194. — Pressure of gas in *inches of water* equals H.

in which it is set free, and for an instant before being consumed, is heated to incandescence. These light sources, therefore, both produce and consume the source of light. Smoking is due to incomplete burning, in which some of the glowing particles escape as "soot." The temperature

of these glowing particles is lower than that of the incandescent lamp filament; consequently, the radiation is made up mainly of heat and the longer lengths of the visible waves. The melted paraffin of the candle and the oil of kerosene lamps are fed to the flame by capillary action in the wick.

Fig. 195. — Thorp gauge measuring gas consumption.

Kerosene may be used in lamps varying in candlepower up to 100. The ordinary upright gas mantle distributes the light more in a horizontal plane, but the burner obstructs the light, causing a shadow just below it. The candlepower may be as high as 60. Inverted mantles throw a good light downward. Small inverted mantles may give 25 candlepower, while large ones, grouped in the same lamp, may give as high as a 1000 candlepower for the one unit.

275. Gas pressure. A fish-tail burner requires a gas pressure of only $\frac{7}{10}$ inch of water. The city gas may be supplied at 2 to 4 inches, but by turning the gas cock part way off, the pressure may be reduced. When the burner is on full, it usually "blows," and less light is secured than when it is turned

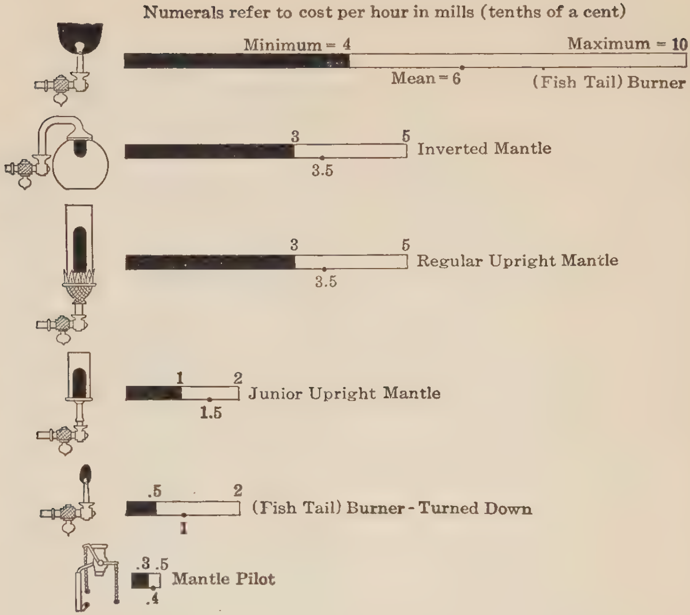


FIG. 196. — Cost of gas used per hour in common gas lighting appliances. Based on gas costing $1.00 per 1000 cubic feet. Variation from minimum to maximum cost due to different sized burners and different gas pressures used. (*Bureau of Standards.*)

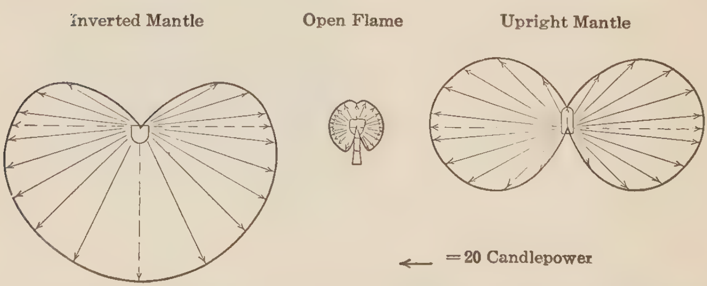


FIG. 197. — Comparison of amount of light from three types of gas lighting, from tests made by the Bureau of Standards.

down until the "blowing" just ceases. The pressure supplied may easily be measured by connecting a U tube partly filled with water to the gas supply, and measuring the column of water supported by the gas. The pressure of the gas in a given burner in use may be obtained by means of the Thorp gauge, which gives not only the water pressure in inches but also the gas consumption in cubic feet per hour. Too much pressure may cause gas mantles to break. Some burners have an automatic device which is lifted, partly closing the gas supply, whenever the pressure increases beyond a safe limit.

276. Gas lighting economy. Comparison of light values and types of burners, under similar conditions, will furnish information of value in selecting the type of gas burner to be used. An apparatus having several outlets will be found convenient for testing burners. Suppose we connect the following: a lava tip, a large upright Welsbach, a Junior Welsbach, a regular inverted mantle, and a "CEZ," or group of three inverted mantles. Let the gas pass through a Thorp gauge just before going to the apparatus. One light after another may be tested and the gas consumption compared. Be sure to test the lava tip with full pressure and part pressure. It will usually be sufficient, for the purposes of this test, to judge the intensity of light by its effect upon the eye; but if accurate measurement be desired, it can easily be made in a darkened room.

277. Electric lighting. The heating effect of the electric current is utilized in the electric lamp. If a short piece of very fine iron or German silver wire is connected across the poles of a dry cell, it will become red hot. If a 10-foot length of No. 26 iron wire is connected to the 110-volt lighting circuit and then gradually shortened, when a suitable length (resistance) of wire is reached, the iron wire will expand from the heat, glow faintly at first, and grow red; then some parts of the wire will get white hot, and probably the wire will melt, breaking the circuit.

The production of light from the heating effect of electricity was known long ago, and was used in a small way for lighting. It was not until 1879, however, when Edison perfected the carbon-filament incandescent lamp, that this form of lighting became a commercial success.

278. Incandescent lamps. The modern incandescent lamp consists of a glass bulb within which is a metal filament. The ends of the filament are attached to wires which pass out through the base of the lamp and connect, one to the metal band with the screw thread on it, the other to a metal plate in the center of the base. The wires are insulated from each other, and the plate is insulated from the outside metal band. When a bulb is screwed into a socket, connection is made with the two wires of the regular electric circuit as in Fig. 152.

279. Units of light measurement. The unit of light intensity at its source is the **standard candle.** Actual standard candles are little used now, but the value of a candlepower is established by standard incandescent lamps. The candlepower of any light source may be determined by comparison with this standard lamp. The process is known as *photometry*, and the apparatus and method may be found in any standard reference book on this subject. In the home we are more interested in the *intensity of illumination* at a given place than we are with the candlepower of the light itself, although there is, to be sure, a relation between the two. The **foot-candle** is the intensity of illumination given by a standard candle at a distance of one foot. The **lumen** is the intensity of one foot-candle upon an area of one square foot.

280. Tungsten lamps. The 25-watt tungsten lamp gives 20 candlepower and hence uses 1.25 watts per candlepower. One dollar will buy about three times as much light when tungsten lamps are used as it would with the old-type or carbon lamps. Tungsten is a better conductor than carbon; hence the tungsten filament is longer and of smaller diameter

than the carbon filament. In addition to the economic advantage of the tungsten lamp, it gives a whiter light, as may readily be seen by placing a tungsten lamp beside a gas light or an old-type carbon lamp; the carbon lamp appears decidedly "yellow" in comparison. That the tungsten light is whiter and more efficient is due to the fact that the filament is heated to a higher temperature. The carbon filament would give a whiter light and consume less electrical energy if its temperature could be raised. But when it is heated higher, it volatilizes and coats the bulb with carbon.

A tungsten lamp with a bulb devised to give a daylight effect uses about 40 per cent more electric current than the ordinary tungsten lamp for the same number of foot-candles. The common household lamps range from 25 watts to 100 watts. The 25-watt, 40-watt, and 60-watt lamps are of the *vacuum type*. The 75-watt and larger lamps are generally "gas filled," that is, instead of having a vacuum they are filled with an inert gas, as nitrogen or argon. A 50-watt gas-filled lamp is also made. Where lamps are so filled, the tungsten may be heated to a higher temperature and thus still greater efficiency as a light source is obtained. Lamps manufactured by the General Electric Company under the name Mazda B lamps are of the vacuum type and Mazda C lamps are gas-filled. When very strong light is needed the larger units give greater economy, as is shown by the following:

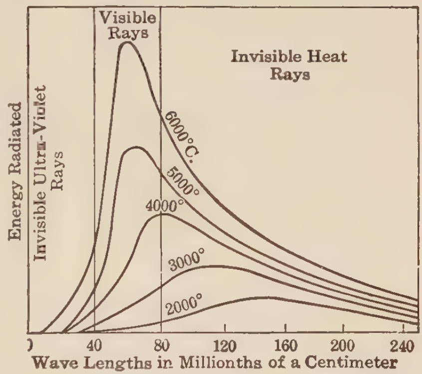


Fig. 198. — The higher the temperature to which a filament can be heated, the greater the ratio of light to heat rays produced.

A 100-watt lamp gives 12.6 lumens per watt.
A 500-watt lamp gives 16 lumens per watt.
A 1000-watt lamp gives 19.8 lumens per watt.

281. Arc lamps. The arc lamp is often seen on streets, and occasionally in stores and in factories; but its place is rapidly being taken by the modern, high-power incandescent lamps, which require less attention and are less expensive to operate. If an electric circuit is closed by bringing the ends of two carbon pencils together and if the two carbon points are then separated slightly, a brilliant light results. The imperfect contact gives a high resistance and consequently a high temperature, and carbon is volatilized. As the carbons are drawn apart a short distance, carbon vapor fills the gap between them and carries the current. This hot carbon vapor is in the form of an arc. It glows, but does not give very much light. The ends of the carbons, however, glow with a brilliant light. When direct current is used, a small crater forms at the end of the positive carbon. This crater is intensely hot and gives much more light than the tip of the negative carbon. If this positive carbon is placed on top, it will throw its light downward in useful directions. This is the arrangement used for street lamps. When the arc lamp is used indoors, the positive carbon is sometimes made the lower one, in order to throw the strong light to a reflector above, which diffuses the light and gives the softer effect of indirect lighting. When the carbons are enclosed in a bulb which is nearly air-tight, they receive less oxygen and so burn away more slowly. The carbons of this **enclosed arc** do not need renewal for one hundred to one hundred and fifty hours, whereas in the open arc new carbons must be put in oftener. By making the core of the carbons of calcium salts, a bright, orange-yellow arc is produced. This is called the **flaming arc.** The arc itself is luminous in this case, and the light is sometimes called the *luminous arc.* For the same consumption of electrical energy, the flaming arc gives about nine times as

much light as the enclosed arc. The lower of two vertical carbons always casts a shadow beneath it. Luminous arc lamps are now made with both carbons inclined from above, so that they converge. Light from this arc is unobstructed.

TABLE XVIII

LUMINOUS EFFICIENCIES FOR VARIOUS LAMPS
(According to Lux)

Lamp	Efficiency — Percentage Total Energy Radiated as Visible Light
Oil	0.25
Gas — upright mantle	0.46
Gas — inverted mantle	0.51
Electric — carbon filament	2.07
Electric — tungsten filament	5.36
Arc lamp — D.C. enclosed	1.16
Arc lamp — D.C. open	5.6
Arc lamp — flaming	13.2

SUMMARY

1. Considerably less than a century ago, there was no better source of artificial light than the candle or the flickering oil lamp.

2. Candles, though relatively unimportant as light sources, are made by the millions today, chiefly for decorations, festivals, and church rites. Kerosene is still the most widely used illuminant. Kerosene and alcohol are both successfully used with Welsbach mantles to give a very bright light.

3. Illuminating gas has been an important illuminant for less than fifty years. When used with the Welsbach mantle, it is one of our best and cheapest lights.

4. Incandescent tungsten electric lamps give excellent light at low cost. Vacuum lamps of 25 to 75 watts and gas-filled lamps of 50 to 100 watts are satisfactory for the household.

5. Arc lamps give powerful lights and have been used extensively for street and store lighting. They are being rapidly replaced by large incandescent lamps placed nearer together, as in this way more even illumination is secured.

6. In the arc lamp two carbon pencils are used. The intense heat produced by their resistance at contact vaporizes some of the carbon, which carries the current when the carbons are drawn apart. The glowing tips of the carbon radiate intense light.

7. One candlepower is the light given by a standard candle. A foot-candle is the intensity of this light at a distance of 1 foot from its source. The lumen is the intensity of 1 foot-candle upon 1 square foot of surface.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. Some defects of gas and electric lighting in the average home.
2. Prepare to argue one side of this question: Resolved that it is better to have a house lighted with gas than with electricity. Consider conveniences, cost, quality of illumination, and fire hazards.
3. Test the illumination from a gas flame under different gas presures, and with different types of mantles.
4. Test the candlepower of lighting by some standard method.
5. Lantern lecture. *The inventor and the lamp.* (Lecture No. 8.) Slides and lecture loaned by General Electric Lecture Service, Schenectady, New York, or nearest office.
6. Motion Picture. *Light of a race.* (Film No. 37.) One reel. General Electric Company.

REFERENCE BOOKS

Barber. *First Course in General Science.* Henry Holt and Company.

Gaster and Dow. *Modern Illuminants and Illuminating Engineering.* The Macmillan Company.

Hunter and Whitman. *Civic Science in Home and Community.* The American Book Company.

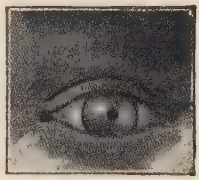
Schraeder. *Incandescent Lamp and its History.* Bulletin L. D. — 118. The Edison Lamp Works, Harrison, New Jersey.

CHAPTER XVIII

ILLUMINATION

282. The eye. In its essential parts, the eye resembles a camera, having a shutter (eyelid), diaphragm (iris), lens (crystalline lens), and a sensitive plate (retina). The amount of light that enters the eye depends upon the opening in the iris, which is automatically regulated. The shape of the lens, too, is controlled by delicate muscles which

Normal eye under right illumination.



Same eye under light with glare.

FIG. 199. — The pupil grows smaller under the stimulus of intense light.

cause the thickening and thinning of the lens, thus shortening and lengthening the focus, as near and far objects are viewed.

In going from a dark to a light room, the iris immediately begins to contract, shutting out the excess of light. Similarly, in going into a dark room from a light one, the iris opens to admit more light. For the same reason, when a person is moving about in a room that is very unevenly lighted, the muscles controlling the iris of the eye are constantly in use, adjusting the eye to the varying conditions of light intensity. These muscles may thus become tired and eye fatigue may result.

The brightness of the average white sky ($2\frac{1}{2}$ candlepower per square inch) is the brightest natural light to which the

eye is habituated through long experience. An intensely brilliant light, therefore, causes the eye to protect itself by such an excessive contraction of the iris that proper vision is possible only through great eye-strain, which, if continued, may work permanent injury. Our eyes are protected by protruding bone and by the eyebrows, from light coming from above. The eye has no such protection, however, from light directly in the line of vision or coming from below, and, therefore, an intense light in either of these positions produces an effect known as *glare*, which, if continued, may prove very injurious. From the preceding statements it will be apparent that a proper intensity of illumination and a correct placing of the lights in a room are of great importance.

TABLE XIX

BRIGHTNESS OF VARIOUS LIGHT SOURCES

Source	Brightness (Candles per Square inch)
Candle	2.5
Kerosene lamp	5. to 9
Gas — fish-tail burner	2. to 5
Gas — Welsbach mantle	25. to 50
Acetylene — 1-ft. burner	53.
Tungsten filament — electric (vacuum)	1000.
Tungsten 50-watt, gas-filled	2600.
Tungsten 500-watt, gas-filled	4500.
Electric arc — crater	8400.
50-watt opal-glass bulb — gas-filled	8.3
100-watt lamp in diffusing globe — 5 inch diam.	4.5
100-watt lamp in diffusing globe — 14 inch diam	0.6
Bowl-enameled lamps, through the enamel	10. to 15
Heavy silk shades over small tungsten lamp	0.1 to 0.2
Average sky	2.5
Sun	600 000.

283. How much light do we need? The intensity of light that is desirable in the various rooms of the home is shown in Table XX.

TABLE XX

LIGHT INTENSITY DESIRABLE IN THE HOME

	Foot-candles
Porch	0.5 – 1.00
Porch, where signs, etc., must be read	2.00– 4.00
Hallway	0.5 – 2.50
Living room, parlor, reception room, dining room, laundry, music room, pantry, kitchen	3.00– 6.00
Chambers	1.00– 3.00
Sewing room	5.00–12.00

The suggested lighting intensities are at best only suggestions. No general statement for lighting a house can cover all cases. It has been found that the best conditions for seeing exist when from 1 to 2 foot-candles reach the eye. If an object reflects but 20 per cent of the light it receives, then it must receive 10 foot-candles to give 2 foot-candles which will be effective on the eye.

The intensity of light needed in a given room varies with the occasion, and the particular use to be made of it. If a test shows 4 foot-candles on the stand before you, the light will be sufficient for reading the newspaper, because newspaper reflects 50 to 60 per cent of the light it receives; but it will not give you satisfactory light for sewing on black cloth, because black cloth reflects but a small part of the light it receives. It is a good plan to have the fixtures and light switches so arranged that certain lamps may be turned on independently of others in the same room.

284. The desk or table lamp. A desk lamp, while desirable from so many points of view, is often a particular source of eye irritation. It is very likely to be placed in the direct line of vision, so that the light itself is a source of glare. Often it throws the light upon the work at such an angle that a glaring light is reflected directly to the eye. If a dense shade covers the light and the rest of the room is very dark, the effect is equally bad, because of the sharp contrast of light and dark whenever the eyes are lifted from the work.

When a table lamp is used, the rest of the room ought to be moderately lighted to prevent sharp contrasts when the user looks up. The sudden adaptation required on glancing from lighted to dark areas is harmful, particularly if frequently repeated. Sharp contrasts may be prevented by using other lights; by having semi-transparent shades, not too dark; or by having an opening at the top of the shade, allowing direct light to pass unobstructed to the ceiling, where it may be diffused to shed a soft light throughout the room. The position of the table lamp with respect to the reader is very

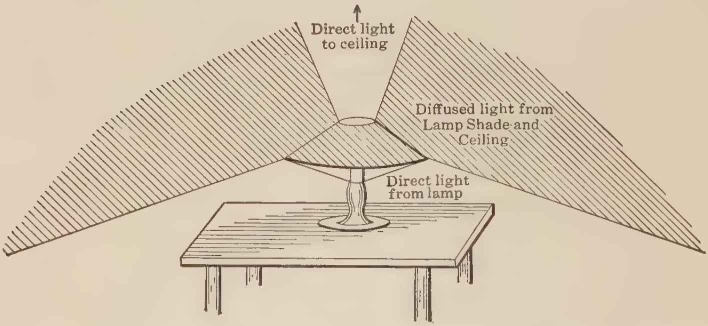


FIG. 200. — Table lamp with shade open at top to send light to ceiling and give diffused light in room.

important. It should never be directly in front so that light from the page is reflected upward squarely into the eyes.

285. Proper lighting. Home lighting should meet the following fundamental requirements:

1. It should be sufficient in quantity and intensity.
2. It should be of proper quality.
3. There should be an absence of glare.
4. The light should be steady; there should be no flicker.

To these requirements should be added the desirable qualities that the light should be dependable and should have low cost.

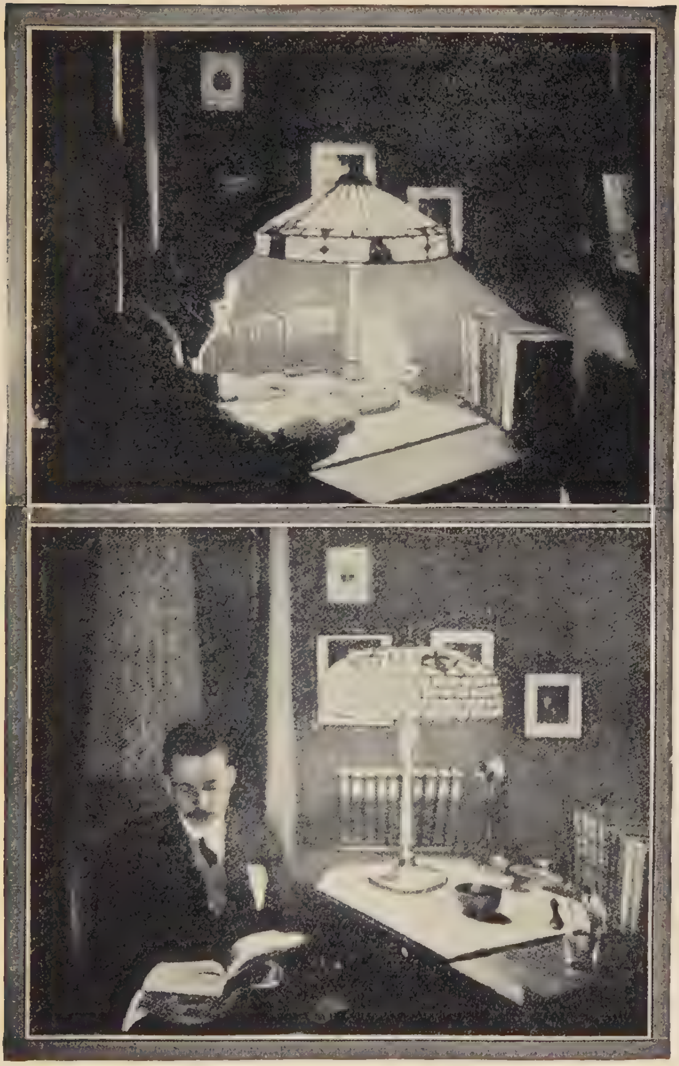


FIG. 201. — Upper picture. Improper illumination for reading. Sharp contrasts and glare. Lower picture. Proper illumination for reading.

286. Intensity. The usual commercial and industrial need for illumination varies from .25 foot-candles to 15 foot-candles, and in some special cases even more. In the home the usual need varies from 0.5 to 4 foot-candles, but if sewing or other fine work is done, 8 or more foot-candles are desirable.

It is not true that *more* light is always better. There is a limit beyond which an increase in illumination does not aid vision; such excess of light is not only wasted but, if the source is within the field of vision, may be injurious to the eye. The intensity suggested in Table XX will be found satisfactory to most people.

287. Quality. All of our common artificial lights, when compared with sunlight, are found deficient in blue and violet rays. This can be considered a disadvantage only in the effect such a light has upon colors. Under most artificial light, blues and purples appear black, and green may appear blue, but reds and yellows show up in their proper colors. The reds and yellows, which predominate in artificial lights, are generally considered more restful to the eye, and it is believed that they promote cheerfulness more than light of shorter wave lengths. The red and yellow wave lengths have great penetrating power; this is seen in observing the sun through a fog or haze. It is for this reason that

Table XXI

VALUE OF VARIOUS LIGHTS IN TERMS OF THREE PRIMARY COLORS

Kinds of Light	Red	Green	Blue
Average daylight	10	10	10
Afternoon sunlight	10	9	6
Welsbach mantle	10	8	3
Gas flame	10	4	0.6
Carbon, incandescent	10	4.5	0.7
Tungsten, vacuum	10	5	1.25
Tungsten, gas-filled	10	7	2

a red light is used as a danger signal on boats and railroads; it can be seen through smoke and steam better than can a blue light.

In Table XXI, gas and electric lights are compared with daylight in respect to their relative proportions of red, green, and blue constituents.

288. Daylight lamps. One fault with most artificial lighting is its failure to give the same colors to our clothing, flowers, and house furnishings that daylight gives to them. This is due to the lack of a sufficient proportion of blue in artificial light. The defect is especially annoying in making purchases of dress goods and neckties, or in matching colors under artificial lights. A **daylight lamp** has been produced for accurate color matching. It has a reflector to concentrate the light downward through a blue-green glass filter. This color filter absorbs those radiations which are in excess, and so produces a light with approximately the same relation of colors found in daylight. It is not an economical light, and therefore is

FIG. 202. — Daylight lamp.

FIG. 203. — Its use in color identification in a store.

unsuited to ordinary home use. It is of value, however, in stores, where knowledge of true color values is important. A lamp which is less accurate in color modification, but which approaches daylight qualities, is the **Daylight Mazda.** This has a blue bulb. The blue glass does not, of course, add anything to the light, but in reality subtracts a good deal in the longer wave lengths absorbed, so that when this lamp is used the lamp wattage must be increased about 35 per cent to secure the same intensity of illumination as when the clear-bulb Mazda C is used.

289. Glare. One of the most important conditions required in good lighting is proper diffusion. Without dif-

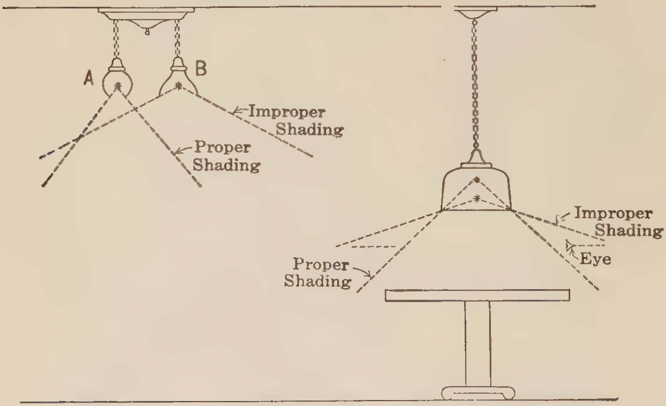


FIG. 204. — Direct glare from light sources is prevented by proper position of lamp in the shade and the right sized opening of the shade.

fusion, glare results. Many people suffer from glare produced by brilliant lights, and they think there is no remedy for it. A strong light against a black background causes much greater discomfort to the eye than the same light against a white background. In rooms where people spend much time, there should be no strong contrast of light upon which the eye may rest. Bare lights at eye-levels are par-

ticularly harmful. Shades for suspension lamps should have a small opening, as *A*, Fig. 204, to prevent the unshaded light from shining into the eyes. All frosted — sand and acid etched — opal, and ribbed globes reduce the intensity

Fig. 205. — Lamp with clear glass gives harsh shadows and much glare.

Fig. 206. — Bowl frosted lamp. Notice absence of sharp shadows and glare.

per square inch by increasing the size of the visible source of light.

The effect of glare in diminishing the visibility of near-by objects is clearly demonstrated as follows: Cut a 6-inch hole

in a large sheet of cardboard; print 2-inch figures about the margin of the cardboard, and around the edges of the hole; cover the hole with wax-paper. In a dimly lighted room, observe that the letters near the hole and far from it are read with equal ease. Place a lighted 100-watt lamp behind the wax-paper. A strong diffused light passes through the paper, causing the iris to reduce the opening into the eye. All the letters are less easily read than before, and those close to the hole are much more indistinct than those at a distance from it.

An objectionable glare frequently results when light is reflected by glossy paint, glossy paper, and the glass of pictures. Coated papers, capable of reproducing half-tone pictures, are now available, and should replace the glossy paper so often used, since they give much less trouble from glare. The means of preventing glare is diffusion, preferably near the source of the light. A lamp recently perfected has a thin, white, hard enamel sprayed over the lower half of the bulb. This reflects the light up into the reflector above, which gives out a pleasing, diffused light. Notice the absence of shadow in Fig. 206. With diffusing bulbs, such as the bowl-enameled, bowl-frosted, and all-frosted, a small amount of light is absorbed, but there is a big gain in one's ability to see clearly.

290. Steadiness and dependability. A flickering light quickly causes eye-strain by calling upon the eye for continual readjustment. Our usual forms of lighting give little trouble of this kind. Sometimes, however, water is condensed in a bend of the gas pipe in sufficient quantity to cause flickering as the gas bubbles through. Water in a gas service pipe occasionally becomes frozen in cold weather, temporarily shutting off the supply of gas. Condensation of naphthaline in the pipe is another source of trouble. If the lights grow dim when the gas range is turned on, the service pipe supplying the house is partly clogged or is too small.

Electric lights never flicker, but the service may be interrupted by the breaking of wires during severe storms. It is well to have some rooms in the house equipped for both gas and electricity, if both are available.

291. Cost of illumination. Kerosene and gas, both used with mantles, supply illumination at practically the same cost. They are the cheapest illuminants. The inconvenience of kerosene is its greatest drawback, and gas and electricity, where available, are more commonly used.

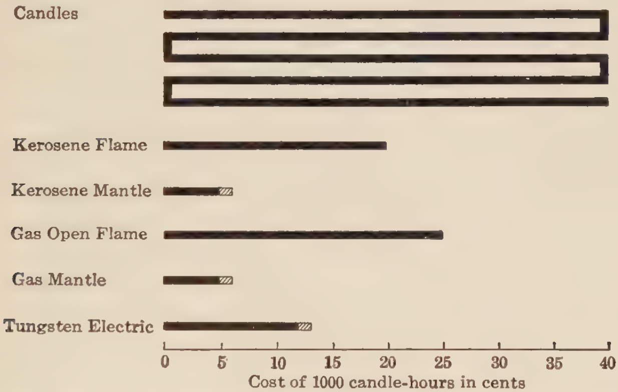


FIG. 207. — Comparison of cost of lighting by different means.

Costs are based on the following prices: Candles, 12 cents per pound; kerosene, 15 cents per gallon; gas, $1 per 1,000 cubic feet; electricity, 10 cents per kilowatt-hour. The solid lines represent cost of fuel or of current, the shaded parts the cost of the mantles and bulbs. (*Bureau of Standards*).

The cost of these varies considerably in different parts of the country, but as a rule gas-mantle lighting is less expensive than electric lighting. The graph, shown in Fig. 207, gives the relative cost of: (1) gas, using different types of burners where gas costs $1.00 per 1000 cubic feet; (2) electricity, using different bulbs when electricity is 10 cents per kilowatt-hour. The actual cost of lighting with the bare-flame kerosene lamp would, for the average family, be less than with electricity. This is due to the fact that when lamps are used much less light is secured. If enough lamps were used

to give the amount of illumination equal to that of the electric lamps, then, as the diagram indicates, the kerosene light would be the more expensive.

292. Shades and reflectors. It frequently happens that a lamp gives but a small part of its light in the place where it is most wanted. It is therefore desirable to redirect some of the light, and perhaps to soften it in some directions. The shade helps to darken portions of the room and the reflector redirects light into places where it is needed. Not only may shades and reflectors bring help and protection to the eyes but, if chosen with regard to their artistic qualities, they give a valuable decorative effect. Opaque reflectors are less pleasing than those which allow some light to pass through. Opal glass and frosted glass are commonly used when a white shade or reflector is desired. Colored or stained glass and colored silk offer an opportunity for selecting shades that harmonize with the other room decorations. All of these should permit enough light to pass through to prevent gloomy shadows, unless there are other light sources to light the rest of the room. The effect of rough surfaces and semi-transparent material for shades, in producing diffused light, is shown in Fig. 208. A rough surface, such as frosted-glass, diffuses light by refraction, and semi-transparent glass, such as opal glass, diffuses the light through reflection and refraction.

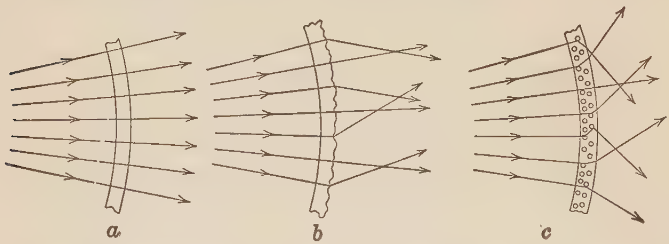


FIG. 208. — Transmission of light: *a*. Clear glass. *b*. Frosted or etched glass. *c*. Opal or milk glass.

293. Efficient lighting. Efficient lighting requires that attention be given to the particular needs of a given place and that those forms of lighting which will serve these needs be chosen. The efficiency of a lighting unit is *the ratio of the light given out to the light at the source.* The selection of lamp shade and reflector is important in this connection. Every time a ray of light is reflected, some of it is lost by absorption. A reflector that sends a ray back and forth several times before it escapes is therefore wasting light.

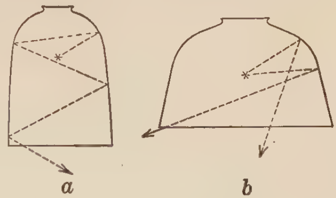


FIG. 209. — *a.* An inefficient reflector. *b.* An efficient reflector.

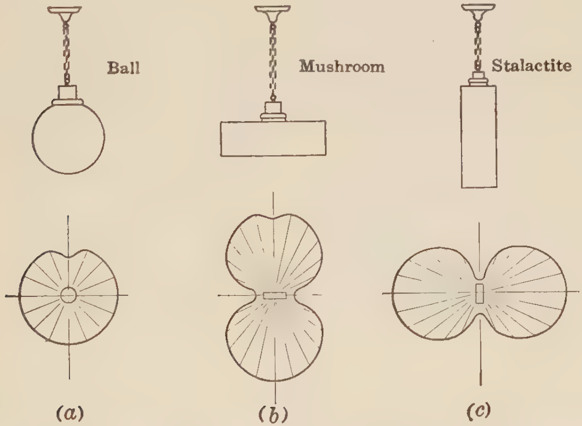


FIG. 210. — Distribution of light: *a.* By a ball. *b.* By a flattened or "mushroom" enclosing luminaire. *c.* By an elongated or "stalactite" enclosing luminaire. Good diffusing glass used in each case.

Dust on the reflectors and shades used in semi-indirect lighting reduces the effective lighting power sometimes 25 to 50 per cent. The general tone of the walls and furnishings has a marked effect upon the amount of useful light we get

from any lighting source. Old, blackened electric bulbs and broken mantles should be replaced with new ones. Tungsten lamps should be used for electric lighting, and gas mantles should be chosen in preference to bare gas flames. The shape of the globe enclosing a lamp has an important effect upon the distribution of light. For even distribution in all directions, a ball shape is best. The "mushroom" diffusing globe, *B*, Fig. 210, gives a strong light upward and beneath the lamp, but very poor distribution at the sides. On the other hand, the "stalactite" type gives a strong light horizontally with but little above and below.

294. Types of lighting. We have come to recognize, in recent years, three types of lighting which are distinguished

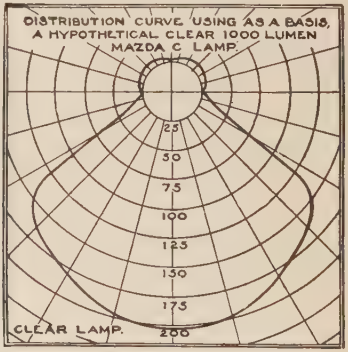


FIG. 211. — Direct lighting. Opal glass shade.

by the manner in which the light is distributed. The three types are the direct, the indirect, and the semi-indirect. In the first of these — **direct lighting** — light comes directly from the source to the place where it is used. There may be a shade or a reflector to throw the light in a useful direction. If the lamp has a clear glass chimney or bulb, the conditions are favorable for glare by reflection from glossy surfaces. From the standpoint of intensity of illumination, this is the most economical type of lighting, and because of its cheap-

ness it is the most common form. In the end, however, the eye fatigue and strain which result may cause it to prove an expensive type of lighting. If the sources of light are high and the individual units well placed, direct lighting may serve satisfactorily in all respects. A form of direct lighting which we may call *diffused direct lighting* is that produced when frosted, opal, or coated bulbs give a diffused light, or when the lamp is enclosed in a diffusing globe.

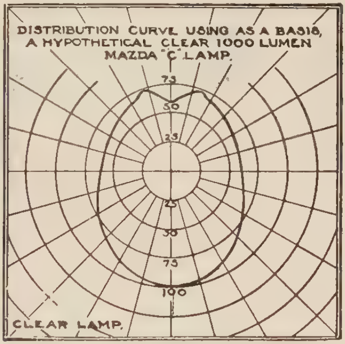


FIG. 212. — Diffused light from enclosing opal globe.

Indirect lighting is produced when all the useful light in the room is obtained by reflection of light from concealed light sources by the ceiling and walls. The concealing device is often an opaque reflector, by which those rays which would naturally come directly into the room are sent to the ceiling, where they are reflected and diffused. This gives a very soft, evenly distributed light throughout the room. This light is much like daylight in its general effect, and it is very restful to the eyes, though some people object to the sharp contrast between the opaque reflector and the brilliant ceiling against which it is seen. This type of lighting is the most costly, because a large part of the light is lost by absorption.

Semi-indirect lighting, or, as it is sometimes called, *direct indirect lighting,* differs from indirect lighting only in sub-

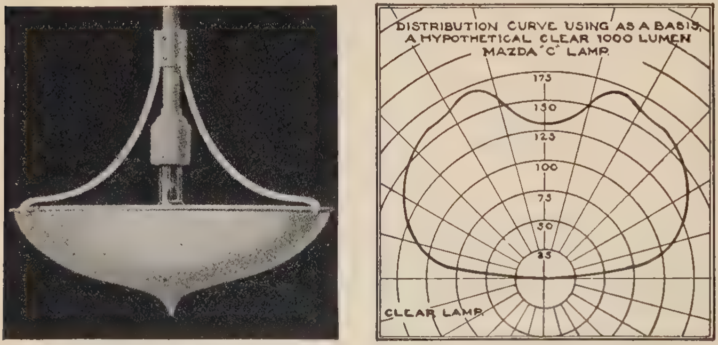


Fig. 213. — Indirect lighting. Enameled steel reflector.

stituting a translucent shade for the opaque reflector of the indirect lighting type. The reflected light from the ceiling mingles with the diffused light which shines through the

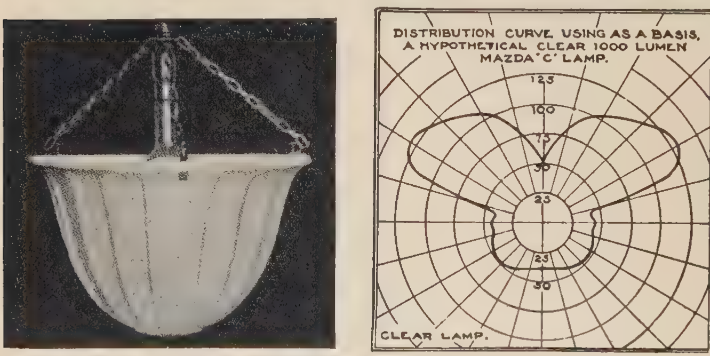


Fig. 214. — Semi-indirect lighting. Opal glass reflector and shade.

shade. As you would expect, this gives a soft, diffused light. It is intermediate in cost of operation, and is a type which can be recommended for general house lighting.

Semi-indirect luminaires* may vary from one with a dense shade, which is very close to the indirect type, to one with a very thin shade, which closely approaches the direct-lighting type. In order to describe a particular kind of luminaire it is better to specify how much of the light is given to the room directly and how much indirectly by reflection; for example, a direct-indirect 30–70 lighting unit means one in which 30 per cent of the light of the room comes directly through the shade and 70 per cent of it comes from the ceiling by reflection.

FIG. 215. — Night view in a well-lighted living room. The central luminaire is supplemented by table, floor and music luminaires.

295. Lighting for shadows. Harsh shadows are harmful to the eye, while equal lighting of all surfaces, without any

* *Luminaire* is a term used to designate a lighting unit and includes fixture, lamp, and shade or globe.

contrasts, makes everything lose form and appear flat and without interest. Under natural, out-of-door illumination, the light from a clear sky received upon a horizontal plane is about one-third that received directly from the sun. Hence it would appear that, if we have our indoor illumination in the same ratio, we shall secure satisfactory lighting. Light from a single lamp, unless diffused light is mixed with it,

FIG. 216. — A night view of the dining room. Notice the even illumination resulting from the semi-indirect lighting.

gives intense, black shadows. But if objects in the room receive one-third diffused light and two-thirds direct light, there will be shadows, but shadows free from strong contrast and therefore pleasing and without discomfort to the eye.

Figures 215 and 216 give examples of good lighting practice and are worthy of careful study.

296. Light and convenience outlets. The electric outlets for a house should be planned before the house is built.

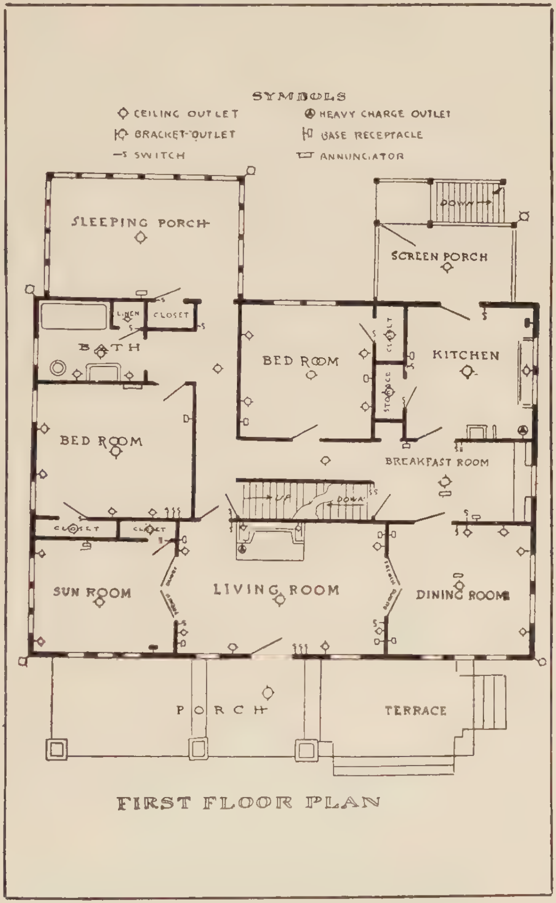


FIG. 217. — Electrical outlets for the first floor.

Side-wall lamp outlets, in addition to the outlet for the suspension lamp, will find a use in practically every room. In most cases, wall lights also add to the attractiveness of a

room. Baseboard convenience outlets are essential for portable lamps, vacuum cleaners, electric fans, and heaters. It is well to be generous in the installation of these outlets. It costs little to install an extra outlet when building, but to add an outlet after the building is completed costs so much that one hesitates to do so. If room heaters, hot-water heaters or electric stoves are to be used, heavy-charge outlets with heavy wires in the circuits are provided because of the greater electrical energy which will be drawn from them. Figure 217 suggests a practical plan for electrical outlets. It will be observed, by examining the diagram carefully, that the closet light switches are in the door frames and are so arranged that, when the door is opened, the light is automatically turned on, and when the door is closed, it pushes the switch and turns the light off.

297. Importance of wall and ceiling surfaces. One may select the right size, number, and location of lamps for lighting a room and yet fail to secure good results because of the walls and ceilings. The surfaces of the room are in reality secondary sources of light, and the effective illumination in a room depends very largely upon the reflection of light from them. A pure white ceiling gives back the most light, but a light-cream tint will often be more artistic and will give satisfactory reflection. Besides being light in color, the finish of the walls should be flat, or matt, rather than glossy. The upper walls may be light colored; but the lower area, within the common range of the eye, should be a darker, neutral color in order that the eye may rest in comfort upon it. One should, however, guard against using too dark wall paper. Exhaustive tests have been made of the reflection from walls and ceilings of various colors and surfaces, and the data of these tests may be found in handbooks on illumination or obtained through decorators and dealers in lighting supplies. Consideration of these data is well worth while when planning the decorations for the home.

SUMMARY

1. The eye has wonderful power to adapt itself to light of different intensities. The iris reduces the size of the pupil as light increases and enlarges it when the light decreases. The eye endures the hundreds of foot-candles that are present in sunlight, and one can read in a fraction of a foot-candle of illumination.

2. The intensity of light we need depends upon what we are doing. Two and one-half foot-candles give good general illumination, but for sewing on dark material 12 foot-candles is not too much. An intense light in the field of vision is exceedingly harmful. The eye should always be protected against direct glare as facing a bare light and against indirect glare resulting from reflection from a glossy surface.

3. Proper lighting is that which is sufficient in amount and good in quality, and gives no glare or sharp contrasts. It must be steady and dependable, and should be inexpensive.

4. Artificial lights are deficient in colors toward the blue end of the spectrum. By using a blue glass or a blue-green filter, the reds are absorbed to such an extent that the light which results approaches daylight in quality.

5. Shades and reflectors are of value in softening and redirecting the light to protect the eyes from glare or contrasts, and to give more light in places where it is needed.

6. Efficiency in lighting is secured by having the proper globe fitted to a lamp, by keeping the dust off the globe, shades, and reflectors, and by selecting proper tones of ceiling, walls, and furnishings.

7. Direct lighting is that in which the light comes directly from the lamp to the work, without being reflected or diffused. In indirect lighting an opaque reflector throws all the light to the ceiling, from which it is diffused into the room. Semi-indirect lighting is a combination of indirect and diffused direct lighting.

8. The walls or baseboards of the house should be provided with a number of electric outlets, to which various electrical conveniences or extra lamps may be attached.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. Glare — its evil effects and the remedy.
2. Pleasing and efficient home lighting.
3. Determine the illumination in the home with a foot-candle meter.
4. Determine, by test with a foot-candle meter, the effect of dust on reflectors and shades.
5. Lantern lectures. *The Lighting of Our Home.* (Lecture No. 11.) *Modified Lighting and its Use.* (Lecture No. 58.) Slides loaned by The General Electric Company.

REFERENCE BOOKS

Gaster and Dow. *Modern Illuminants and Illumination Engineering.* The Macmillan Company.

Powell. *The Effect of Color of Walls and Ceilings on Illumination.* Bulletin L. D. 102. Edison Lamp Works.

Powell and Smith. *Residence Lighting.* Bulletin L. D. 137. Edison Lamp Works, Harrison, New Jersey.

CHAPTER XIX

OPTICAL DEVICES OF THE HOME

298. Sight-aiding devices. Civilization has brought many problems, not the least of which are those which relate to better vision. We of today have many needs not known to people of the remote past. Science and invention have well provided for the needs of civilized man in meeting his new and larger problems. This is particularly true in the field of sight-aiding devices. Where is there a home today that cannot make a good display of such devices? There is the reading glass or a simple magnifying glass; the eyeglasses or spectacles; the opera glass and field glass; the stereoscope; the telescope or spyglass; the camera, perhaps a toy periscope, and possibly a "bull's eye" lantern.

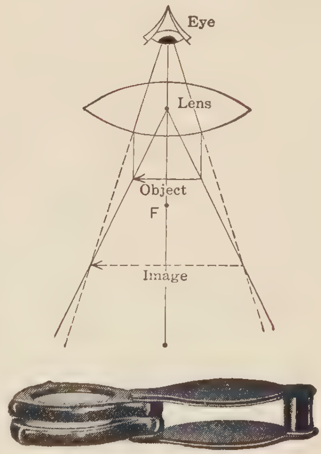


FIG. 218. — A simple microscope and how it makes an image larger than the object.

Thanks to science, we can, by using the proper instruments, see some of the unseen. Bodies remote from the earth, invisible to the naked eye, are brought within our range of vision. Near-by bodies, so small that they cannot be seen, are enlarged until they are visible. Defects of the most important optical instrument of all to mankind, the eye, may be remedied by the use of artificial devices. In all these instruments and devices, the most important part is the lens.

299. The reading glass. The reading glass is a form of simple microscope with a long focus. The microscope lens has a greater curvature and shorter focal length than the reading glass. In both the reading glass and the small microscope, the object to be seen must lie between the lens and the principal focus. The microscope must be much nearer to the object than the reading glass, because of the shorter focus of the microscope lens. The diagrams of Fig. 218 and Fig. 219 show why the image is larger than the object.

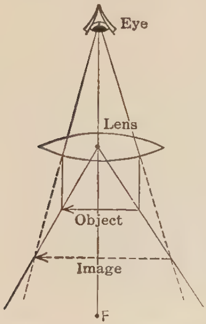


FIG. 219. — How the reading glass magnifies.

FIG. 220. — The reading glass is a simple microscope.

We judge the size of a body largely by the angle made in the eye between the rays of light from the extreme ends of the body. By bending the rays of light, the lenses of the reading glass and microscope increase the angle at which the rays of light from the object enter the eye. In this way an enlarged image is produced.

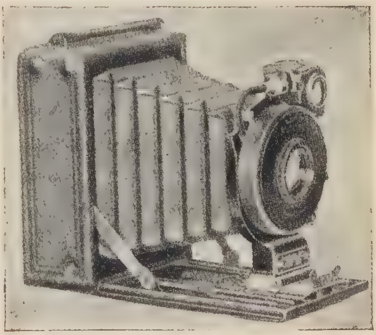


FIG. 221.— A common type of camera.

300. The camera. The camera is much like the human eye, but while the retina of the eye can hold its image but a fraction of a second, the film or plate of the camera can be so treated that the picture will be permanently preserved.

The analogy between the camera and the eye is striking. The camera is a light-tight box, having a shutter in front of the lens, through which light may be admitted or excluded at will. There is a diaphragm which regulates the size of the opening through which light enters the camera. In the front of the camera there is a lens, and when the operator is ready to take a picture, a sensitive plate or film is placed in the back. The film corresponds to the retina of the eye.

301. Camera lenses. A single lens is found in the cheapest cameras. The violet rays (actinic rays) are the ones that make our pictures, but most of the visual rays by which

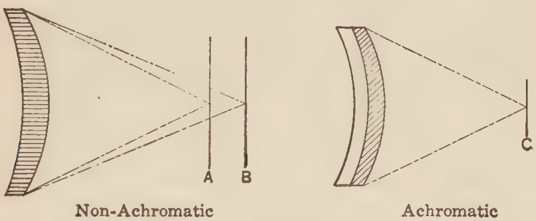


FIG. 222. — Single meniscus lens at left and double combination lens at right.

we see objects come from the red end of the spectrum. A single lens, used wide open, focuses the actinic rays at *A*, Fig. 222, but the visual rays by which we focus the picture are focused farther away, at *B*. Since flint glass bends the actinic rays more than crown glass does, it is possible to combine a negative flint lens with a positive crown lens so that the actinic or chemical rays and the visual rays are focused at the same point, or at *C*. Such a lens gives no separation of colors and is called an **achromatic lens.**

Only three sizes of stops are used with single lenses: the largest for ordinary snapshots; the medium for shapshots of views on the water, or for time exposures; and the smallest for time exposures only.

The single lens tends to distort straight lines, particularly the marginal lines of the picture; this is sometimes seen in the vertical lines in the photographs of buildings. It is not so apparent in small pictures as in large ones. This distortion is corrected by using a double combination lens, the parts being separated by the diaphragm. This is the rapid, **rectilinear lens** shown in Fig. 224. The largest opening that can be used with the rapid rectilinear lens is stop 8.

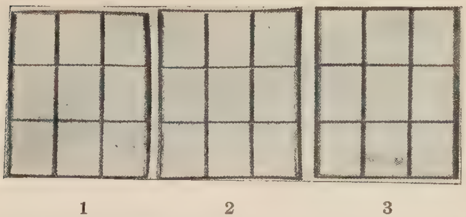


FIG. 223. — Parallel lines distorted by meniscus lens (1 and 2). Stop back of lens (1). Stop in front of lens (2). The rectilinear lens gives no distortion (3).

Lenses that are more highly corrected than the rapid rectilinear lenses, so that they may be used at larger apertures than stop 8, are called **anastigmats.** A rapid rectilinear lens can be used with an opening with a diameter up to $\frac{1}{8}$ its focal length, but an anastigmat will give sharp pictures with an opening having a diameter $\frac{1}{7}$ its focal length. This larger opening admits 60 per cent more light in the same time and so cuts down the time of exposure. It makes snapshots possible on dull days or even indoors. Such lenses, however, are expensive.

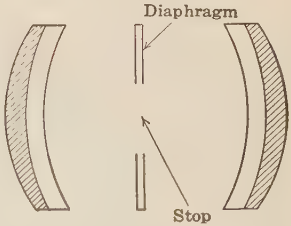


FIG. 224. — Double combination of lenses used in the rapid rectilinear lens.

302. The diaphragm and " stops." The size of the opening by which light may pass through the lens is determined by the *diaphragm.* By mechanical means a variety of

openings of different sizes may be secured. The various openings are termed *stops.* The small stop allows only the center of the lens to be used. This is the best part of the lens and gives a clear, distinct image. As the size of the stop is increased, more of the outer edge of the lens is used. Only expensive lenses will give a sharp image at the largest stop. Stop 8 is a large opening and 32 is small. If one second is the correct exposure at stop 8, two seconds will be required at stop 16, and four seconds at stop 32.

303. The focus. In Fig. 225, *A* is the focus for objects 10 feet from the lens, and *B* the focus for objects 100 feet from the lens. If the focal length of the lens is 3 inches, the distance between *A* and *B* is $\frac{3}{16}$ inch, but if the focal

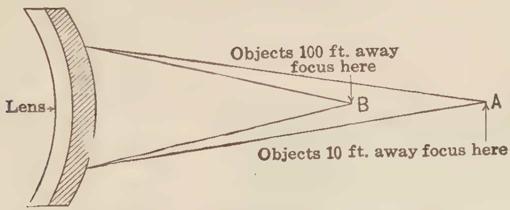


FIG. 225. — Position of image depends upon distance of object.

length is 12 inches it is $1\frac{3}{4}$ inches from *A* to *B*. If a camera has a lens with 3-inch focal length and the plate is placed half-way between the two focal points *A* and *B*, no matter at what distance the object is, it will be very little out of focus. Such a lens is used in **fixed focus cameras** to take pictures up to $3\frac{1}{4}$ by $4\frac{1}{4}$ inches. With the size of stop used in these cameras, no blurring due to poor focus can be detected, and the camera has the advantage of always being in focus. With a focusing camera the size of stop used is important. If you have focused upon an object 15 feet away with a large stop, objects 10 feet and 20 feet away will be somewhat blurred; but as you reduce the opening, they become sharper, and at stop 32 all objects 10 feet away and beyond will be clear and distinct. For artistic effect, an

object in the foreground may be in sharp focus while the background is indistinct. This result is obtained by using a large opening and focusing upon the near-by object.

304. The finder. The camera finder, like the camera, has a lens and a screen which receives the image. In one

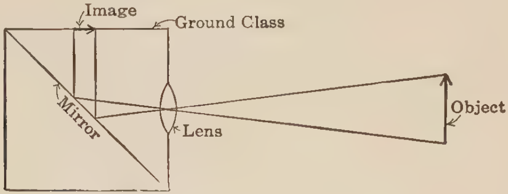


FIG. 226. — The camera finder.

form, a mirror placed at an angle of 45 degrees reflects the light rays from a horizontal to a vertical direction, and fixes the image on a horizontal ground glass surface. In another type, the "brilliant," the image is focused on a screen within the finder, where it is viewed by looking through a lens. Both finders show just how much of the view will appear in the picture.

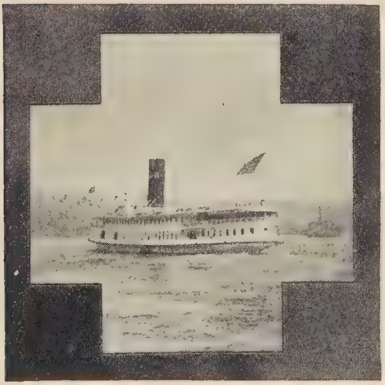


FIG. 227. — Image in the finder. Well placed for horizontal picture.

305. The compound microscope. Two lenses are used in the compound microscope. The smaller of these has a short focal length and is called the **objective**; the larger is the **eyepiece**. When the microscope is focused for use, the object is placed at a distance greater than the focal length and less than twice the focal length of the objective. A real,

inverted, and enlarged image is produced at some place between the two lenses. This image must also lie between the eyepiece and its principal focus. The eyepiece thus acts as a simple magnifying glass and magnifies the enlarged image of the object. This double magnifying process makes it possible to so enlarge many invisible bodies that they may be seen. A study of Fig. 228 will make clearer how the compound microscope works.

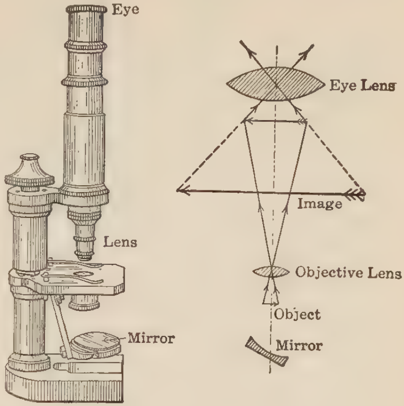


FIG. 228. — The compound microscope.

306. The telescope. The telescope has at least two lenses. The objective has a large diameter to admit much light, and it has a long focus. The eyepiece is small and is used as a simple microscope to magnify the image produced by the objective lens. The object is at a greater distance from the objective than twice its focal length; hence the image is smaller than the object. It is inverted and real. The image is magnified by the eyepiece sufficiently to make it appear larger through the telescope than to the naked eye. In the astronomical telescope the image seen is inverted. For land use an extra lens is placed within the barrel of the telescope, in order that objects may appear right side up.

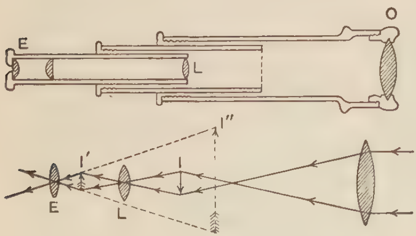


FIG. 229. — An erecting telescope.

307. Field glasses. Field glasses and opera glasses are made on the same principle as Galileo's telescope, which he constructed in 1610, and with which he could magnify 30 diameters. Galileo's telescope differs from our present telescopes only in the eyepiece. Galileo used a double-concave lens instead of a double-convex lens. The concave lens is placed between the objective and its principal focus. This causes the rays to diverge, so that as they enter the eye they make a larger visual angle, and so magnify the object. The opera glass commonly used, has a double concave eyepiece and magnifies from three to four times. High-power field glasses of this type are awkward to carry because of the long barrel necessary.

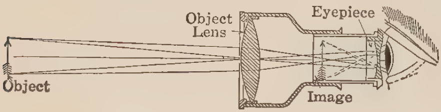


FIG. 230. — Opera glass.

308. Prism binocular. This compact field glass, having the power of an ordinary field glass or telescope of nearly three times its length, is made possible by the use of two right-angle prisms. The lenses used are the same as in the telescope. The image is brought right side up through the reflection in one prism, and corrected for reversal of right and left by the second prism, so that as seen the image is perfectly natural.

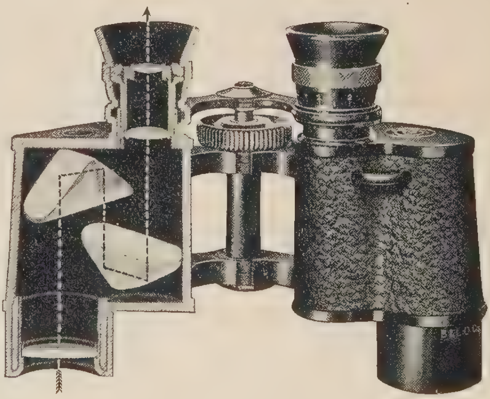


FIG. 231. — Prismatic construction and path of light rays in the binocular.

Fig. 232. — Field of the binocular (above) and field of the ordinary glass (below).

309. The stereoscope. Since our eyes are several inches apart, each eye sees a slightly different picture. A landscape looks flat when seen through one eye alone; but when

it is seen with both eyes, relative distances are more apparent and the view has what we call *depth*. An ordinary photograph taken with a one-lens camera is flat, even though seen with both eyes. To remedy this fault, a camera with two lenses, separated by a distance equal to that between the two eyes, is used to take two pictures simultaneously. These two pictures are mounted beside each other and viewed through the stereoscope. Both pictures are seen at once, each through a prism lens so arranged that the two images coincide. Since each eye sees the same image that it would if observing the real object, the sense of depth or distance is very apparent. Objects in the picture are slightly magnified and stand out clearly in relief.

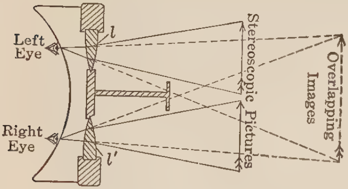


FIG. 233. — The Stereoscope.

310. The periscope. A simple periscope requires only two mirrors, facing and parallel to each other, placed some convenient distance apart and at an angle of 45 degrees to the line of sight. For protection, it is better to have the mirrors inside a hollow tube, with openings properly placed for the passage of light from the object to the eyes. Field glasses may be used in place of direct vision. Except as a toy, the periscope is of no use in the home, but its use in the submarine and in the trench makes it invaluable in war.

311. Lenses for eye defects. Tests show that there are very few normal eyes. Some people see near-by objects most clearly, and are therefore said to be **near-sighted.** Others see distant objects most clearly, and are said to be **far-sighted.** A clear, distinct image can be seen only when the image is focused on the retina. Focus adjustment for distant bodies consists in relaxing the muscles and allowing the lens of the eye to flatten or become thin; *for near bodies,*

the lens must be thickened to produce the proper focus. When the normal eye is relaxed, parallel rays of light focus on the retina. When a person is near-sighted, these parallel rays *focus in front of* the retina. This defect results from inability to make the eye lens thinner. A concave lens in front of the eye may be used to correct the defect, since it reduces the convergence of the rays and thus makes them focus farther back. When a person is far-sighted, the parallel rays *focus behind* the retina. This defect results from inability to thicken the lens sufficiently to bring the focus forward to the retina. A convex lens in front of the eye gives the effect of a thickened eye lens and is used to correct far-sightedness.

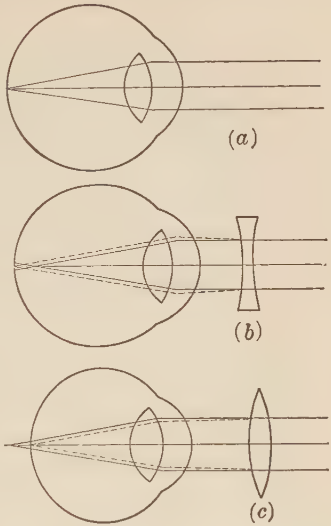


FIG. 234.—Differences in normal eye (*a*), the near-sighted eye (*b*), and the far-sighted eye (*c*). The dotted lines show the path of the rays after correction by glasses.

Near-sightedness, called **myopia,** occurs when the eye-ball is so elongated that the lens is too far from the retina, while far-sightedness, called **hypermetropia,** occurs when the eye-ball is too short from front to back. The cornea of the eye is often flatter in far-sighted than in normal eyes.

If the curvature of the cornea or of the lens is uneven, all the rays which enter the eye will not focus at the same place. This makes it impossible to see all parts of an object clearly at the same time. While some parts will be seen distinctly, other parts will appear blurred. This defect is known as **astigmatism.** A lens for the correction of astig-

matism must be prepared for each individual case. Where there is a flat place on the cornea there must be a convex place on the lens, and where the cornea bulges out the lens must be made concave.

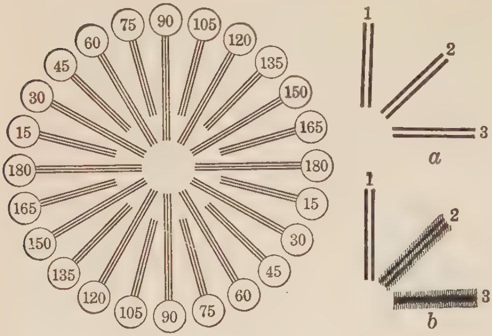


Fig. 235. — Wallace's chart for determining astigmatism (reduced). (*a*) Appearance of lines to normal eye. (*b*) Appearance of lines to the astigmatic eye.

312. Eye-glasses. In ordinary eye-glasses, the edge of the glass is farther from the eye than the middle; consequently, when one turns the eye to see objects through different parts of the glass, a change in focus of the eye must be made. By use of a concave-convex lens, known as the **toric lens,** the eye is more nearly equidistant from all parts of the glass. This not only reduces the amount of refocusing, but also increases the field of vision.

As a rule, elderly people need two pairs of glasses, one for seeing near objects, the other for seeing distant objects. Since near-by work is seen by looking downward, and in distant vision the eyes are raised, it is possible to combine the two sets in one pair of glasses. These are the **bifocal glasses.**

For any eye defect the lens must be fitted to the eye which is to use it; *only those who have specialized in this work should be trusted to prescribe for ones's eyes.* A skilled oculist can tell the trouble and prescribe the remedy; the optician can prepare glass lenses according to the oculist's prescription. Many eye defects, if attended to while one is young,

may be kept from growing worse, and some of them may be cured. Neglect of small eye troubles will bring serious ones later on.

313. Automobile headlights. The parabolic reflector is a great aid to automobile lighting. With it, a bulb of a few candlepower can be made to throw a beam of thousands of candlepower. This is possible because the light coming to the reflector is collected and condensed by it into a powerful beam. If the source of light were a point and were situated at the principal focus, the reflected light theoretically would pass off in parallel rays, giving a beam of light equal in diameter to that of the reflector, as shown in the lower half of Fig. 236. In practice, the source of light is greater than a point and the surface of the commercial mirror is not a perfect parabola, so that the resulting beam of light is a diverging beam. In the upper part of Fig. 236 is shown what actually happens. From each point on the reflector, as at P, a cone of light is reflected. The axis of this cone, PX, is parallel to the principal axis of the reflector. The beam of light given by the automobile headlight lamp is then the resultant of countless cones of light united into one slightly divergent beam. By means of a suitable lens in front of the lamp, this beam may be directed downward to light the road and not into the eyes of passing autoists. The " pick up " distance for light and dark objects is discussed on page 367. Relatively few headlights are free from

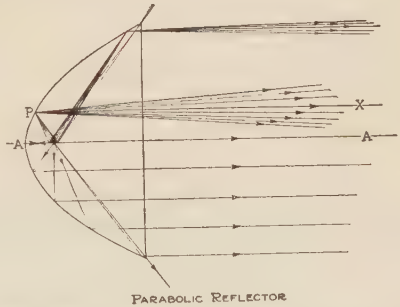


FIG. 236. — Lower half. Theoretical distribution of light from a luminous point at principal focus. Upper half. Actual distribution from a lamp at the principal focus.

glare on a dark highway, but if the highway is well lighted the dangers resulting from glare are largely removed.

314. Stereopticon. The stereopticon, by which pictures, either of the still or the moving type, are thrown on the

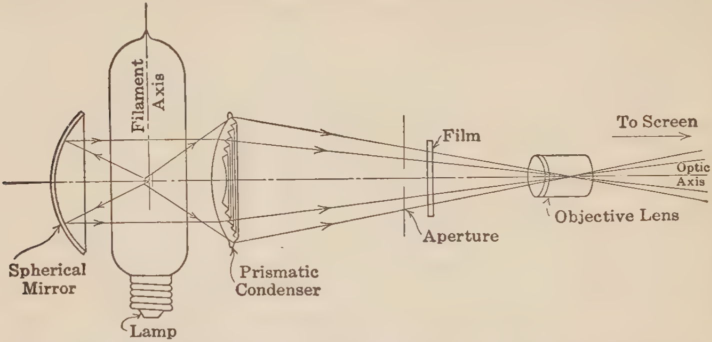


FIG. 237. — Arrangement of essential parts of a projection lantern

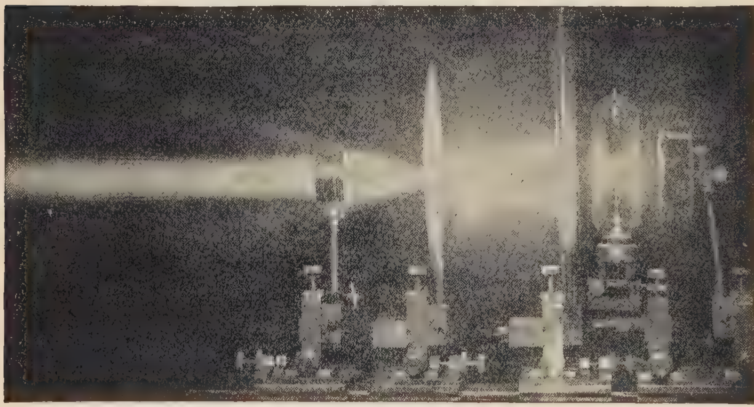


FIG. 238. — Light beam in picture projecting system using a prismatic condenser.

screen, has a powerful light. If the light used is an incandescent lamp, a concave mirror is placed back of it. Just in front of the lamp are the **condenser lenses,** whose purpose is to pick up the angular rays of light from the lamp, covering

a large area, and throw them forward in a slightly converging beam into the **projection lens.** The condensers increase enormously the amount of light which enters the projection lens, and thereby greatly increase the intensity of light on the screen. The positions of these parts will readily be seen by consulting Fig. 237. The lantern slide, inverted, is placed just in front of the condenser lenses. By moving the projection lens forward or backward a clear picture is secured on the screen at some distance in front.

SUMMARY

1. The reading glass and the simple microscope consist of a double-convex lens. When an object, placed under the lens within its focal length, is viewed through the lens, it appears much enlarged.

2. The essential parts of the camera are a light-tight box, a lens with shutter, diaphragm, and a place for a plate or film at the end opposite the lens.

3. The cheapest cameras have a single lens. A better lens, which is called *achromatic,* is made by combining a flint-glass lens with a crown-glass lens. The *rapid rectilinear lens* is the next higher quality and consists of a double combination lens whose parts are separated by the diaphragm. The *anastigmat* is an expensive lens which has been so highly corrected that it can be used at a much larger opening and so reduce the time of exposure.

4. A focusing camera is one having a lens with a relatively long focal length. The universal-focus camera has a lens of so short a focal length that whether the objects to be photographed are near or far they are all in fairly good focus.

5. The compound microscope uses a lens to magnify the enlarged image of a second lens, the objective. The telescope is the same in principle, but the objective has a longer focal length than that of the microscope. The image is

seen inverted, but by introducing a third lens it may be seen erect.

6. Field glasses and opera glasses are in principle like the telescope, but are arranged for the use of both eyes. By using right-angle prisms for reflecting light, the length of the field glass is greatly reduced.

7. The stereoscope is a device for making pictures show depth, as if the original were seen directly. This is accomplished by taking two photographs, one representing the object as seen by the right eye and the other as seen by the left, and then viewing these two, one with each eye, through a magnifying glass of low power.

8. The periscope makes use of double reflection by two parallel mirrors having a 45-degree angle to the line of sight, in order to enable an observer to see over or around obstructions.

9. Far-sight is a defect which causes distant objects to be seen more clearly than near ones. The far-sighted eyeball is too short, and the lens cannot be thickened sufficiently to bring the image of a near object forward to the retina. The remedy is a convex lens placed in front of the eye.

10. Near-sight is a defect which makes it impossible to see objects clearly unless they are near the eye. The near-sighted eyeball is too long, and the lens cannot be made thin enough to bring the focus of a distant object back to the retina. The remedy is to place a concave lens in front of the eye.

11. Astigmatism is the most common eye defect. It can be remedied by corrections applied to a lens to correspond to the defects in the eye cornea or lens.

12. Toric lenses give a larger field of vision than common lenses. Bifocal glasses combine near- and far-sight lenses in one pair of glasses.

13. The automobile headlight is a powerful beam produced by reflection. By passing this beam through the

proper lens, we can direct it downward and thus remove much of the objectionable glare.

14. In the stereopticon and moving picture machines, lenses are used to concentrate a strong beam of light upon the curtain. These lenses must be of the right focal length to give a clear image of the picture which is on the slide or film.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. Through the telescope.
2. Through the microscope.
3. The periscope — the eye of the submarine.
4. Measure the magnifying power of a small telescope or field glass.
5. Motion picture projection.

REFERENCE BOOKS

Black. *Experiments in Practical Physics.* The Macmillan Company.
Butler. *Household Physics.* Whitcomb and Barrows.
How to Make Good Pictures. Eastman Kodak Company.

CHAPTER XX

THE HOME WATER SUPPLY

315. Source of water supply. Directly or indirectly, the source of our supply of water for domestic and industrial purposes is rain. In some country homes a rain barrel is still used, while in many more rain is collected from the roof but stored in a cistern. By means of suitable devices, the first roof wash can be automatically discarded and the clean water collected and stored. If this stored water is safeguarded against pollution, it makes a satisfactory home supply. It is soft water and so does not waste soap.

The rain water that remains on the ground or later comes to the surface in lakes and rivers is a source of water supply for our larger towns and cities. The main supply for the country home is that rain water which is soaked into the earth and is later taken from springs and wells.

316. Wells. Water sinks quickly in a porous soil, such as sand; but compact soils, for example a very clayey soil, resist the movement of water. A layer of clay, like a layer of rock, is practically impervious to water. When water soaks into the ground, it will at some depth encounter an impervious layer, and for some distance above this the soil will become saturated with water. The surface of this water, known as *ground water*, is called the **water table.** In some places the water table will reach the surface and a body of surface water may be found there. In other places the water table may be a few feet below the surface, while in still others you might dig a hundred feet and not encounter water. The water table, as might be expected, varies with the season of the year, moving upward during times of plentiful rainfall and sinking during the drouth. A **well**

is a hole dug into the earth to a depth below the water table. The water table marks the level to which the well will be filled with water.

317. Artesian wells. Alternate layers of porous and compact soil are of frequent occurrence. Owing to geological changes in the earth's crust, these layers have been folded, in many places, so that one of the given series of layers will be, perhaps, thousands of feet higher than another distant part of the same layers. Erosion may have left the high part exposed, and here rain will enter the porous layer. In time the water, confined in this porous layer by the impervious layers above and below, will rise within its limited

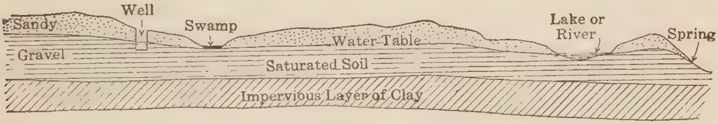


FIG. 239. — Rainwater stored in the soil supplies wells and springs with water.

space until it stands at a level which is higher than the surface of the land at some distant point. If then this layer is tapped by boring a hole into it at its lower level, the pressure of water standing at the high level, even though this be miles away, will cause the water to gush forth in a constant flowing stream. Some artesian wells are more than a mile in depth.

318. Springs. Sometimes a break in the upper impervious layer allows water from the porous layer below to escape. When this reaches the surface of the ground, it makes a *spring*. Springs more commonly result when the water table reaches the surface on a hillside. Many hillside springs cease flowing in dry weather because of the falling of the water table. Spring water and well water have certain soluble materials taken from the soil, and in a given locality are of the same general character.

319. How the country house is supplied with water. When a house is located under a near-by hill, it is usually a simple matter to locate a spring or well above the house level, so that water will flow, by force of gravity, through a pipe to the house. This method takes advantage of the well-known principles that "water runs downhill" and that "water seeks its own level." Water will rise in pipes to the top floor of the house, if this is not higher than the source.

Besides the old-time bucket and windlass, there are many types of pumps in use for raising water from a well which is lower than the house. The most common of these is known

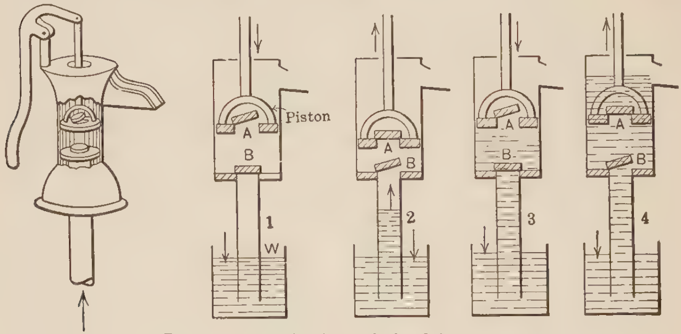


Fig. 240. — Action of the lift pump.

as the **lift** or **suction pump.** Its operation depends upon the pressure of the atmosphere. A pipe extends from the barrel of the pump into the water in the well, Fig. 240. At the top of the pipe, where it joins the barrel, there is a valve, *B*, opening upward. Inside the barrel is a tight-fitting piston with a valve, *A*, also opening upward. On the *down stroke* of the piston, the air between the two valves is compressed and opens valve *A* to escape. On the *up stroke* of the piston the overlying air holds valve *A* tightly closed. The rising piston increases the space below it, and so decreases the pressure upon the valve *B* and also upon the water inside the pipe extending below the valve. The

pressure of the atmosphere on the surface of the water in the well, W, pushes water into the pump to equalize the pressure. On the next down stroke of the piston the lower valve closes and the upper valve opens, allowing air or water to pass through it. After a few strokes, the barrel is filled with water and the water is lifted until it runs out of the spout.

Since the atmosphere cannot lift a column of water more than 34 feet high, piston and valve A must not rise more than 34 feet above the water surface; in practice, 25 to 27 feet is about the limit, instead of 34 feet. This is due to leakage around the valves, to dissolved air which escapes from the water when the pressure is removed, and to the fact that water vaporizes in increasing amounts as the pressure is reduced. When the valves have become dry, it is frequently necessary to add a little water to the pump to start the action. This is known as *priming*.

320. The spray pump. A type of force pump described in Section 321 may be used to produce a stream of liquid under high pressure. With a suitable nozzle this stream may be broken into a fine, mist-like spray. Another type of spray pump depends upon the principle of the atomizer. When a strong current of air is blown from a jet tube, it reduces the pressure immediately surrounding the current of air near the end of the tube. If the narrowed mouth of a second tube is close to the air jet and its lower end is immersed in a liquid, atmospheric pressure will force the liquid through the tube, provided the tube is short. When the liquid meets the jet of air it is scattered in fine spray.

FIG. 241. — Sprayer.

321. The force pump. A common type of force pump is shown in Fig. 242. A solid piston is moved up and down in the barrel of the pump. An outlet pipe, containing a

valve, A, connects with the barrel near the bottom. This leads to an air dome, C, from which the delivery pipe takes the water to any desired place. When the piston is raised, the pressure below it is reduced. Back pressure from the delivery pipe keeps the valves in the outlet pipe closed. Atmospheric pressure forces water up into the barrel of the pump, opening the valve B. On the down stroke the lower valve, B, is closed and the water is pushed out through the

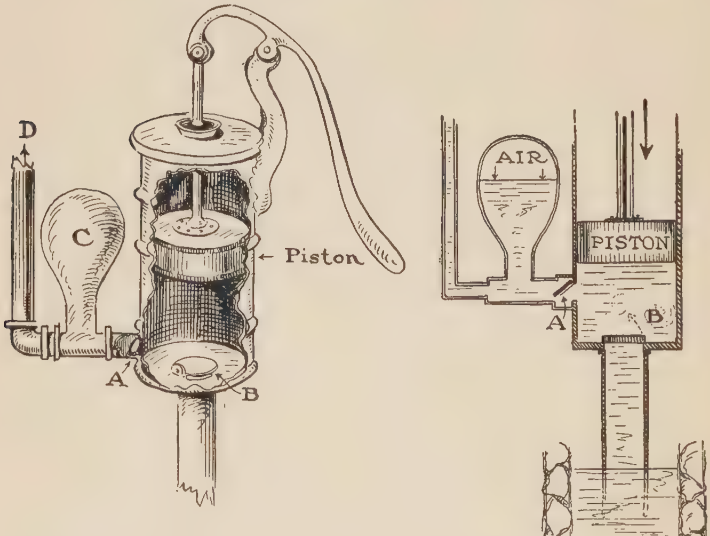


FIG. 242. — The force pump.

outlet valve, A. A part of the water compresses the air in the air dome and a part goes directly out through delivery pipe. During the next up stroke, the compressed air in the air dome forces water out, so that a continuous flow from the delivery pipe results. Force pumps are used for lifting water to high levels, for delivering water under high pressure, and for spraying purposes.

322. Hydraulic ram. A hydraulic ram is an automatic pump which raises water to a higher level than its source.

It can be used only where there is an abundance of water, for it works on the principle that a large amount of water falling a short distance can raise a small amount of water a greater distance. When water flowing in large volume from the source, through the overflow valve *A*, Fig. 243, reaches a sufficient speed, it lifts and closes the valve. The momentum of this running water is so great that a portion of it is forced through the delivery valve *B*, into the air chamber. Here it compresses the air and eventually passes on through the delivery pipe to the storage tank, from which it may be distributed by gravity.

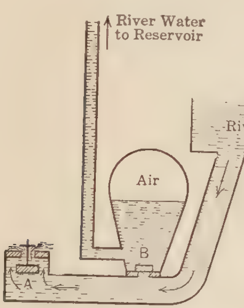


Fig. 243. — Hydraulic ram.

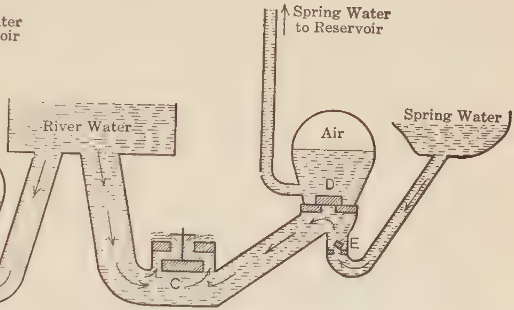


Fig. 244. — Another type of hydraulic ram.

By means of a ram of slightly different construction, river or lake water may be used as the source of power to drive pure spring water into the supply tank. A study of Fig. 244 will show how this ram works. When valve *C* is open, spring water and river water both run out. The space in the vicinity of valve *D* is entirely filled with spring water; when *C* closes, the back pressure closes valve *E* and forces spring water through valve *D*.

323. Pressure tank. Where there is no city water supply, the convenience of such distribution may be secured by use of the *pressure tank*. This is a large, air-tight tank of iron, and is usually located in the cellar. There are two pipe

connections near the bottom of the tank, one being the inlet and the other the outlet. The force pump, driven by hand or by power, is used to force water from its source into the tank. At the start the tank is full of air. As water enters, the air is compressed into smaller space, its pressure increasing all the time. If water fills the tank half full, the pressure of the confined air is doubled; that is, its pressure is equal to 2 atmospheres. When water flows

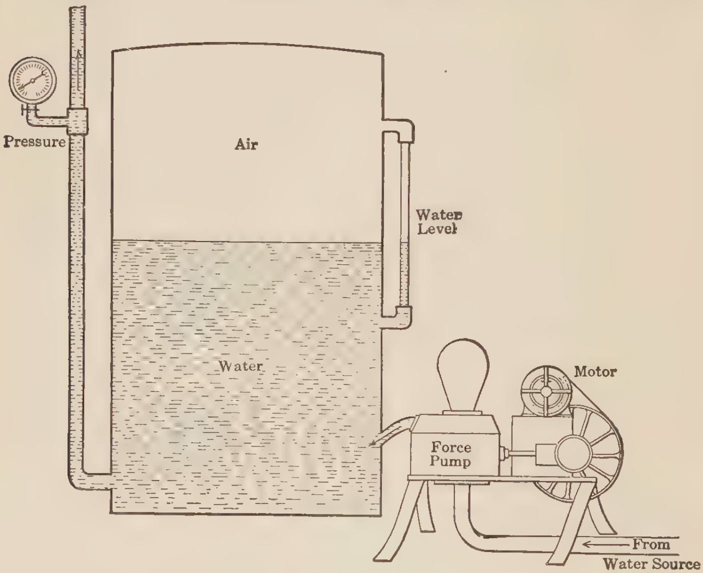


Fig. 245. — The pneumatic tank.

out of faucets it must overcome a pressure of 1 atmosphere. This would leave a pressure of 1 atmosphere available to lift water in the pipes to the floor above. Since the *pressure of a gas varies inversely as its volume*, when the tank is three-fourths full of water and the air occupies but one-fourth its original volume, the air would be under a pressure of 4 atmospheres. This would give a force of 3 atmospheres available for lifting water. If we recall that 1 atmosphere

is able to sustain a column of water 34 feet high, it will be seen that a tank three-fourths full of water is under sufficient pressure to lift a column of water 100 feet high. If faucets were placed at the same level as the tank, water would be delivered at a pressure of 45 pounds per square inch. Pressure tanks have a water gauge at the side to show the water level within. A glance at the gauge will indicate whether or not it is necessary to pump more water in. Automatic devices may be installed to keep the water at a constant level without any personal attention, and a pressure gauge will indicate the water pressure.

324. City water supply. Small cities and towns sometimes obtain enough water to supply their needs from springs

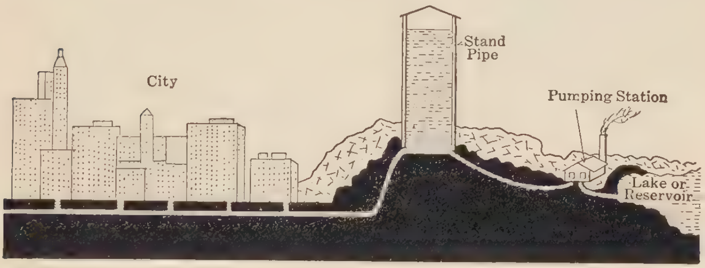


FIG. 246. — The stand pipe is at a higher level than the tallest building it supplies with water.

or wells, but usually it is necessary to go to rivers or lakes for such supply. In exceptional cases a lake may also serve as a reservoir from which the city may be supplied directly by gravity, but as a rule a **pumping station** is necessary. When water is to be used at a place as high as its source, or higher, it must be pumped to a **reservoir** or **standpipe,** sometimes to both. Many river and lake supplies are so impure that the water must pass through settling basins and then be filtered, before it is safe for domestic use; in some cases the water is made fit for use only by subsequent chemical treatment.

325. Power pumps. The pump most commonly seen at pumping stations is the **double-action force pump** driven by steam power. The operation of this can readily be understood from Fig. 247. This pump is powerful and delivers a fairly steady stream. It is capable of lifting water to high elevations. For low lifts, such as drawing water from a river to the settling basin along the bank of the river, **centrifugal pumps** may be used. These pumps will deliver a large volume of water, but will not raise it to a great height. The centrifugal pump has blades attached to the hub of the rotor. As the rotor is driven, suction is created around a center where the inlet pipe is attached. Atmospheric pressure lifts water into the pump. The rotating blades then whirl the water toward the outside of the blades, whence it leaves through the discharge pipe. The pump somewhat resembles an electric fan enclosed in a metal case, or better, perhaps, a water wheel driven backwards. For an individual supply in the country the same plan of a pump and storage tank is used. Small lift pumps and force pumps are used, and may be driven by windmills, hot air engines, and gasoline engines.

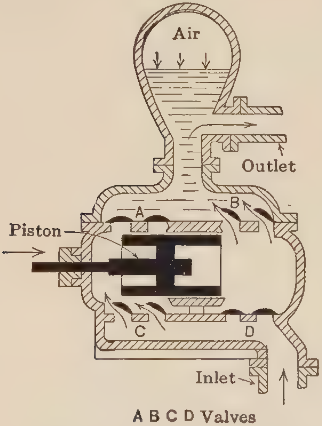


FIG. 247. — Double-acting force pump used in water pumping stations.

326. Water pressure. The pressure in any house depends upon the difference in level between the house and the standpipe or reservoir supplying water. If the water in the reservoir is 100 feet above the faucet, we may expect the pressure due to the weight of a column of water 100 feet high, or about 40 pounds per square inch. This is

enough to run small water motors for polishing or grinding, and for washing-machines. In apartment houses, the pressure varies with the floor, being lowest on the top floor and highest in the basement. The pressure at any given faucet may be decreased when much water is being used at the same time by others who draw from the same service pipe. Some sections of hilly cities are so high that water from the reservoir will reach only the lower floors. If running water is to be supplied to the floors above, a private pumping system with a tank must be installed.

327. Household water fixtures. In the piping of a house for water, there are many details which, if not properly

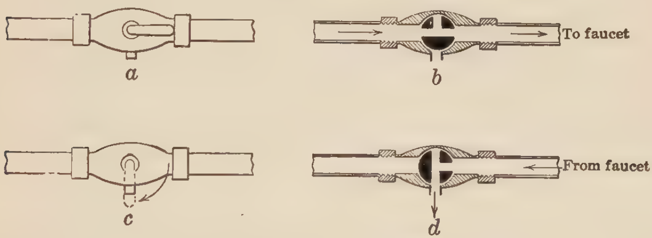


FIG. 248. — How the cut-off valve shuts off the water and drains the pipe to the faucet at the same time.

attended to in advance, may always be a source of annoyance. One of these is the location of faucets. Outside faucets on opposite sides of the house, and one in the basement or cellar, will be found convenient. There should be one **main cut-off** by which all the water can be shut off from all the pipes. There should be a cut-off for each outside faucet, to be used in cold weather. It is also an advantage to have a cut-off for each of several different divisions of the water-pipe service, so that when repairs are being made it will not be necessary to shut off the water from all the house.

When water runs from an open faucet, a long stream of water is in motion through the pipe. This moving water has such momentum that, if the faucet is quickly closed, the

sudden check on the water produces an unpleasant sound in the pipes, known as *water hammer*. If " dead end " pipes, filled with air, are used in suitable places, the force of the moving water will be used up in compressing the air in these ends and all annoyance will be avoided.

The flow of water from the pipes is controlled by means of faucets. There are two types in common use, both of which have proved very satisfactory: they are the **screw type** and the **spring type.** In both of these the opening is closed by a leather or composition washer. By turning the handle of the screw faucet or pressing the handle of the spring faucet, the washer is moved away from the opening. This allows water to flow. When the washer is worn thin or becomes loosened, it will vibrate as the water runs out. Sometimes the thread of the screw faucet becomes so worn that it is loose and vibration is caused. Vibration from either of these sources produces sound which is extremely annoying. New washers will remedy the difficulty in one case, but if the screw threads are loose, it will be necessary to have entirely new faucets in order to remove the trouble.

SUMMARY

1. The source of the water used in the household is rain. This is true whether we have a cistern or a well, or draw our supply from springs, rivers, or lakes.

2. The surface of the ground water is called the water table. The level of the water varies with the amount of rainfall.

3. An artesian well is made by tapping a porous layer which lies deep in the earth below an impervious layer. The water works its way along this layer from some distant place where the porous layer is open to the surface and can receive rain water.

4. Springs result when the water table reaches the surface on a hillside, or when a crack in an impervious layer

allows water from below to rise through it and come to the surface.

5. The house is supplied with water by gravity when the source is higher than the house. In other cases water is usually pumped.

6. The suction pump, by a series of valves, produces a vacuum into which atmospheric pressure forces the water. The water is then raised by a moving piston to the desired elevation.

7. The force pump, by an arrangement of valves slightly different from that used in the lift pump, forces a column of water to a great height. An air dome joined to the delivery pipe makes a continuous flow possible.

8. The common spray pump works on the principle of the atomizer. A strong air jet across the mouth of a second tube, which extends into a liquid, creates suction, with the result that atmospheric pressure sends the liquid up the second tube and the air current spreads it in a fine spray.

9. The hydraulic ram is a device for automatically lifting water to a higher level than the source.

10. Air pressure in a closed tank will distribute water to all parts of a building. The air pressure is secured by compressing the air above the water, by pumping more water with the tank.

11. Double-acting force pumps, driven by steam, are used in water-supply pumping stations.

12. The water pressure in a city water system depends upon the elevation of the reservoir or standpipe above the place where the water is used.

13. The water system in each house should have several cut-off valves, in order that the water may be cut off from certain parts of the house or from the entire house, when it is necessary to repair faucets, tanks, or connections.

14. Two important types of faucets are the screw type and spring type. The dripping of water from a faucet can usually be stopped by placing a new washer in the faucet.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. Underground waters.
2. Ancient water systems.
3. The local water-supply system.
4. Make a model pump.
5. Water power.

REFERENCE BOOKS

Baker and Ware. *Municipal Government of the City of New York.* (Chapter 11.) Ginn and Company.

Garnett. *A Little Book on Water Supply.* Cambridge University Press. (Macmillan.)

Gerhard. *Water Supply of Country Houses.* W. P. Gerhard, 40 East Forty-Second Street, N. Y. City.

Lynde. *Home Water Works.* Sturgis and Walton Company.

CHAPTER XXI

MACHINES OF THE HOME

328. How machines aid in doing work. Whenever we apply force, as in lifting a body, the force we apply must be equal to the weight of the body and must be applied through the same distance as that through which the body

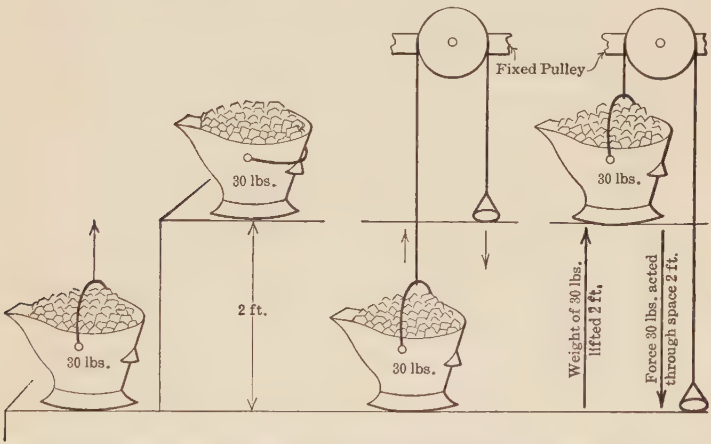


FIG. 249. — The fixed pulley changes the direction of effort, but not the amount of force applied.

is moved. The **work** on the body is calculated by multiplying the weight by the distance it is lifted. Obviously, this equals the force exerted times the distance through which it acts. The unit of work is the *foot-pound.* It is the work done by a force of 1 pound acting through a distance of 1 foot.

Work (in foot-pounds) = *force* (in pounds) × *distance* (in feet) *through which it acts.*

Suppose we pass a cord over a fixed pulley and, by pulling down on one end of the cord, lift a hod of coal weighing 30 pounds, attached to the other end. A spring balance will show that we must exert a force equal to the weight, and measurement will show that the force acts through a distance just equal to that through which the weight has moved. The only advantage of the fixed pulley is that it

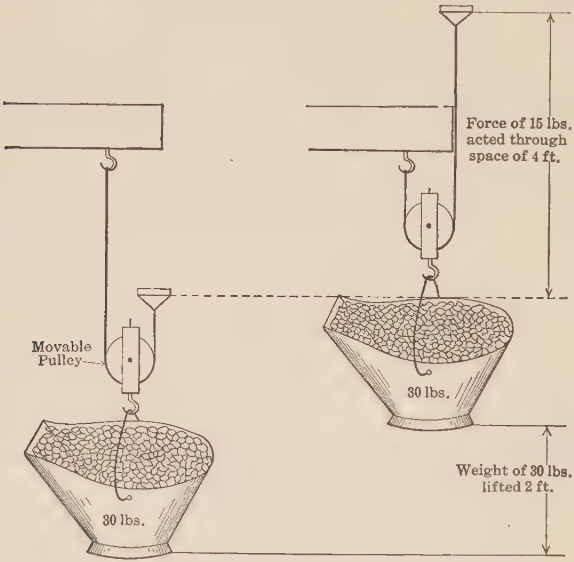


Fig. 250. — Advantage of a movable pulley.

has enabled us to change the direction of the force, for with it we pull down, whereas without it we should be obliged to lift.

Now suppose we attach the hod of coal to the block of a movable pulley, fasten one end of the cord to an overhead beam, and lift on the other end of the cord as in Fig. 250. When we measure the force required to lift the weight in this manner, we find that it is only *one-half that of the weight*, or 15 pounds. When we measure the distances, we find that *the force has acted through twice the distance that the weight*

has moved. The weight lifted was 30 pounds, and it was moved 2 feet; hence the work done on the weight would be 30×2, or 60 foot-pounds. The force was 15 pounds and it acted through a space of 4 feet; hence 15×4, or 60 foot-pounds of work was done.

The work done upon any machine always equals the work accomplished by it if we neglect friction.

What, then, is the advantage of the machine? The mechanical advantage of the machine lies in the fact that we can accomplish a piece of work by expending a smaller force through a greater distance, as is illustrated above.

329. Lever-type machines. The crowbar, the tack lifter, the nut cracker, the potato ricer, the can opener, and the clock hands are examples of the simplest type of machine, the *lever;* they all belong to the same type of machine as our old friend the "teeter" board or "see-saw." This is so familiar that it may well serve to help us understand the principle involved in the simple lever. With no one aboard, the plank just balances. A 150-pound person 6 feet from the center just balances another 150-pound person 6 feet from the center on the other side. Now let one bend backward so that his center of weight is 6 feet 2 inches from the

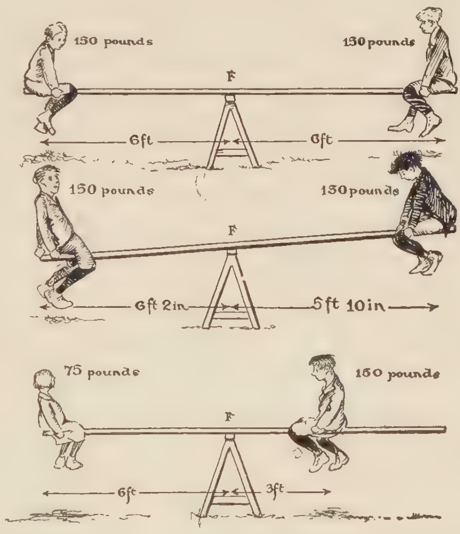


Fig. 251.—Lever principles illustrated by the see-saw.

center, and the other bend forward so that his center of weight is 5 feet 10 inches from center. In either case a turning movement about **F** the **fulcrum,** takes place: one sinks and the other rises. Replace one of the persons by a 75-pound person, up goes the 75 pounds and down the 150 pounds. But let the 150-pound person come in to the 3-foot mark and there is exact balancing. It is observed that $150 \times 6 = 150 \times 6$, where equal weights are at equal distances, and that $75 \times 6 = 150 \times 3$, where one person weighing half as much as the other, balances the other by being twice as far away from the fulcrum. By further experiments we could secure data to verify the law which has already been determined, namely:

In all lever machines balance is secured when force 1 (*resistance*) $\times$ *its distance from the fulcrum equals force* 2 (*effort*) $\times$ *its distance from the fulcrum.*

Now let us apply this to a few machines for doing real work. The pump handle shown in Fig. 252 is a lever, and if the piston rod is pulling in a line 3 inches (perpendicular distance) from the fulcrum and the effort applied perpendicular to the handle is 2 feet (24 inches) from the fulcrum, the pump handle has a **mechanical advantage** of $\frac{24}{3}$, or 8. That is, the 8-pound resistance at the piston is balanced by a 1-pound force (effort) 24 inches away. The product of resistance by its distance equals the product of effort by its distance; $8 \times 3 = 24 \times 1$.

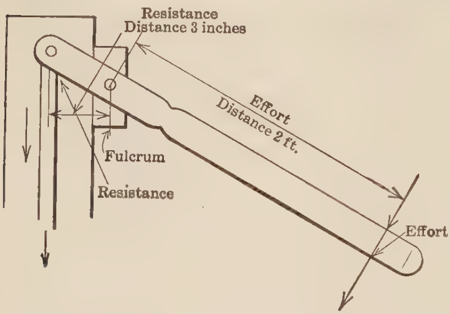


Fig. 252. — The pump handle as a lever.

The case of a hammer used in drawing a nail is illustrated in Fig. 253. In all lever machines the distance considered

must be *the perpendicular distance from the fulcrum to the line of direction in which the force is acting.* The nail offers resistance in a line 3 inches from the fulcrum. The effort

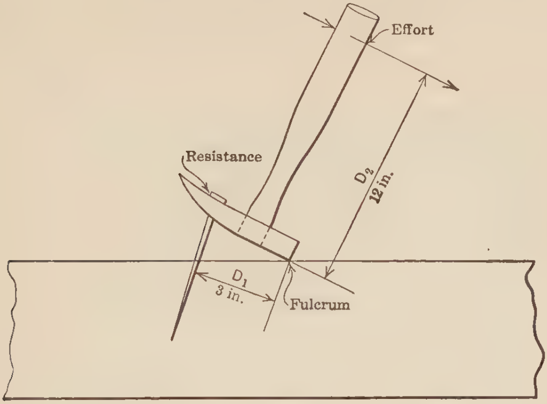


FIG. 253. — The hammer as a bent lever.

applied to pull the nail is acting in a line 12 inches from the fulcrum. If the effort is measured and found to be 20 pounds, then the resistance offered by the nail may easily be determined as follows:

$$20 \times 12 = \text{resistance of nail} \times 3$$
$$240 = \text{resistance of nail} \times 3$$
$$\text{Resistance of nail} = \frac{240}{3} = 80 \text{ pounds.}$$

The wheelbarrow is a lever machine. The axis of the wheel is the fulcrum. If a barrel of flour weighing 196 pounds is centered over a point 2 feet from the fulcrum and a man lifts on the handles 5 feet from the fulcrum, how much effort must he

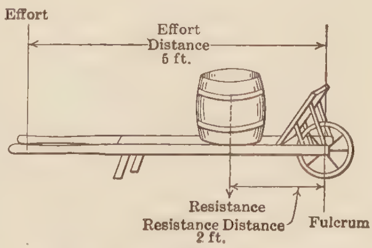


FIG. 254. — How does the wheelbarrow illustrate the lever type of machine?

exert to lift the flour, neglecting the weight of the wheelbarrow itself?

$$196 \times 2 = \text{effort} \times 5$$
$$392 = \text{effort} \times 5$$
$$\text{Effort} = \frac{392}{5} = 78.4 \text{ pounds.}$$

Three different arrangements of the relative positions of effort applied, resistance, and fulcrum are possible with levers. These are:

(1) The fulcrum between the effort and the resistance.
(2) The resistance between the fulcrum and the effort.
(3) The effort between the fulcrum and the resistance.

These three arrangements are illustrated respectively by the scissors, the boiler safety valve, and the forearm, in

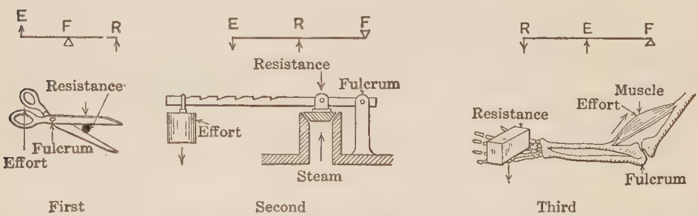


FIG. 255. — Three types of levers, depending upon the position of the fulcrum in relation to effort and resistance.

Fig. 255. Study a number of devices, as the piano and typewriter key mechanism, a lemon squeezer, sugar tongs, grass shears, can opener, etc., and determine the position of the fulcrum, effort, and resistance for each.

330. Advantages of the lever. As was shown in the preceding section, one of the important reasons for the use of the lever is its **mechanical advantage,** whereby one may overcome a resistance much greater than the effort he applies. It is always true, however, that just as much work must be done *on the lever* as is done *by it,* and that when a

smaller effort is applied, it must act through a correspondingly longer distance. This may be expressed in the form of an equation:

Effort × distance through which effort is applied = Resistance × distance through which the resistance is overcome.

Or:

$$E \times \text{Distance } E \text{ is applied} = R \times \text{Distance } R \text{ is overcome.}$$

Another advantage of the lever is **speed advantage.** The baseball bat illustrates this; one hand acts as the fulcrum, the other as the force. The force is applied on the short arm

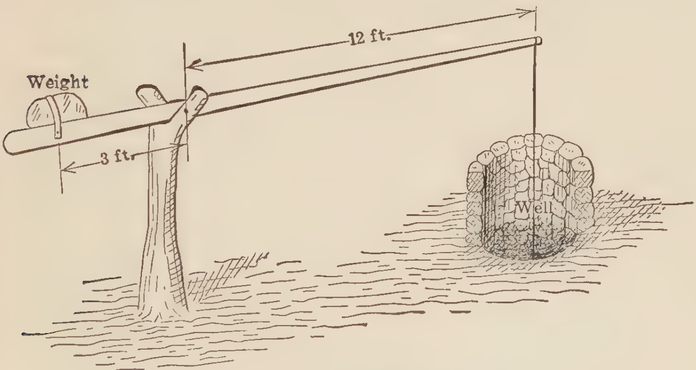


FIG. 256. — The well sweep is a lever.

of the lever and the long arm has greater speed, which is an advantage in driving the ball a long distance. In the human arm, the biceps muscle is attached to the forearm bone a short distance in front of the elbow, which acts as the fulcrum. By contracting this muscle one is able to move the hand rapidly through a long distance, and graceful arm movements are possible. Our arms would be awkward indeed, if we were compelled to do without this type of lever. In what other parts of the body are levers found?

For speed advantage the work equation of the lever, $E \times$ Dist. E is applied $= R \times$ Dist. R is overcome, may be

expressed $E \times$ Speed of $E = R \times$ Speed of R, since as the motion occurs in the same length of time, the speed is proportional to the distance passed over.

Problem. An old well-sweep, Fig. 256, has a heavy weight 3 feet from the fulcrum. This acts as force to lift water in a pail attached to the other end of the pole, which is 12 feet from the fulcrum. If the heavy weight falls 4 feet, how high will the pail be lifted?

Solution. The weight and applied force are not given, but from the two arms, 3 and 12, we know that, neglecting friction, they must be in the ratio of 12 (effort) to 3 (resistance). Let X equal distance pail will be lifted.

$$3 \times X = 12 \times 4$$
$$3X = 48$$
$$X = 16$$

The pail would be lifted 16 feet.

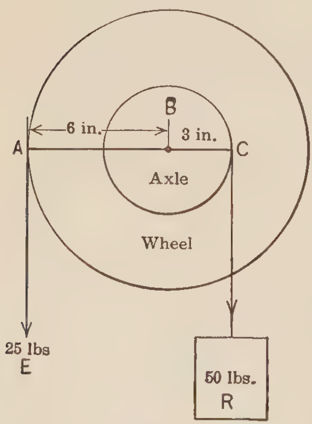


FIG. 257. — Use this diagram to explain how the wheel and axle is in principle a continuusly acting lever.

331. Wheel and axle. In the ice-cream freezer, the clothes wringer, egg beater, bread mixer, churn, emery knife sharpener, and windlass, we apply effort in the path of a large circle or at the circumference of a wheel while the resistance is applied at the circumference of an axle. A machine of this type differs in no respect from a lever in principle; in fact, it is a continuous-acting lever, as may be seen from Fig. 257. Let B be the center of both axle and wheel, A is the point of application of the effort (E) on the wheel, and C the point of application of the resistance (R) on the axle. Then at any instant AB is the effort arm and BC is the resistance arm.

AB is the radius of the wheel and BC is the radius of the axle. We may solve wheel and axle problems by applying the law of levers previously given.

332. The pulley. Little use is made of the movable pulley in the home, though we do sometimes use it for awnings and hammocks, and the fixed pulley is used to support the cord running to the window weights. The pulley is another modified lever, as will be seen from Fig. 258. Each sheaf of the pulley is an equal-armed lever. The block and tackle used for moving buildings, pulling stumps, lifting safes and pianos, may have many strands of rope between the movable and fixed blocks. The effort is applied through as many times the distance through which the resistance is overcome as there are strands of rope going from the movable block; hence:

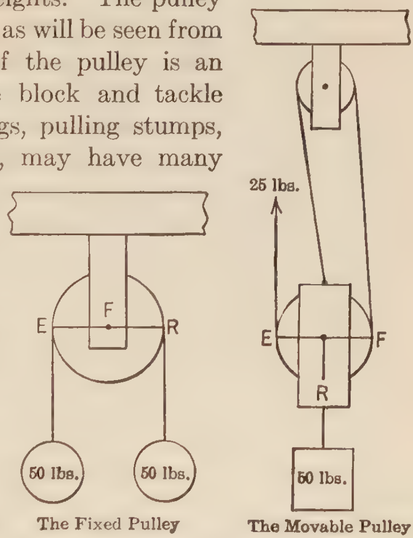


FIG. 258. — The lever principle in the pulley.

The mechanical advantage of a system of pulleys is equal to the number of ropes which come from the movable block.

333. The inclined-plane type of machines. Machines of this type, such as the **skid** used in loading and unloading trucks, the **wedge** of which the **ax** is an example, and the **screw,** all work on the principle of the inclined plane. The principle in brief is this: The work done in lifting a body is calculated by multiplying the weight by the vertical height to which it is raised. If the weight is not lifted vertically, but is moved along an inclined surface, the force required to move it is less, because the force acts through a distance

which is greater than the vertical height to which the weight is lifted. When the force acts in a direction parallel to the incline, then:

$$Wt. \times vertical\ dist. = Force \times length\ of\ incline.$$

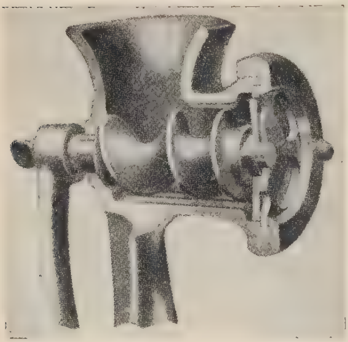


FIG. 259. — The screw principle is used in the food chopper to force the food against the cutting knives.

The principle of the inclined plane is well illustrated in the case of mountain roads. A long road with gentle grade is preferred to a short road with steep grade, because of the greater mechanical advantage of the gentle grade. The screw is a spiral inclined plane. The corkscrew and meat grinder make use of the screw principle.

334. Complex machines. Many kitchen devices and farm tools are very simple machines, but we also find numerous machines which are so complex that it is difficult to recognize in them any of the simple machines we have mentioned. And yet the sewing machine, the piano player, the automobile, and the reaper are only applications and combinations of various forms of these simple machines. Close examination of individual parts will reveal many surprising facts previously unknown to the user of the machine. There are many devices in common use which involve other scientific principles besides those of the simple machines; ex-

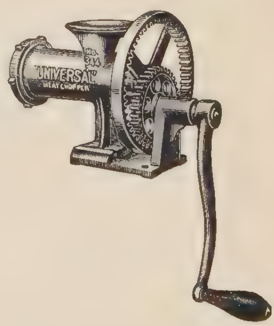


FIG. 260. — Wheel and axle with gear combination.

amples of such devices are the washers and cleaners. Often gear combinations are used as a means of changing speed. In many machines used in the household, the great advantage is the employment of power other than hand power, such as water power, electricity, etc., in their operation. Among such may be mentioned dish-washing and clothes-washing machines and vacuum cleaners.

335. Efficiency of machines. In practice we are unable to get as much useful work out of a machine as we put into it. Friction cannot be eliminated entirely, and a certain amount of energy must be expended in overcoming it.

The ratio of useful work done by a machine to the work done upon it is known as the efficiency of the machine.

If the work accomplished by the use of a machine is but three-fourths of the work actually done, its efficiency is 75 per cent. In some cases friction may be reduced by the use of roller bearings and lubricants, which thereby increase the efficiency of the machine. Ball bearings are found in roller skates and in the bicycle. Roller bearings are used in heavy machines, as in parts of the automobile.

336. Vacuum sweepers and cleaners. The use of these devices depends upon atmospheric pressure. A partial vacuum is produced within the machine by pump action or a motor-driven turbine. If the opening to the vacuum chamber is in the vicinity of loose dirt, the inrushing air will carry the dirt in with it. The air pumped in or drawn out of the vacuum chamber is returned to the room through a closely woven cloth bag which strains the air and holds all the dirt and dust inside. The hand-operated and the smaller electrically operated machines are "sweepers." They do little more than remove the surface dirt. The "cleaners" are those machines with enough power to really clean rugs and carpets so that removal for beating is unnecessary. The advantages of vacuum cleaning are: less hard work, less dusting, and more healthful air. A permanently installed

cleaner is best, but as this means a large outlay for the machine and piping to all the rooms, the smaller portable machines are more commonly used.

337. Demonstration of the vacuum principle. The following demonstration will explain the working principle of the vacuum cleaner. Partly exhaust a large bottle, such as shown in Fig. 261, by means of an air pump. Close *A*. Hold *C* over powdered chalk and coarse sand, and open *B*. The atmospheric pressure causes a rush of air into the bottle, forcing the chalk dust through the pipe with it. Exhaust the bottle as completely as possible and repeat on another mixture of sand and chalk dust. This time both chalk and sand particles are pushed in. The higher the vacuum, the stronger the force of the air, and the heavier are the particles which may be moved by it.

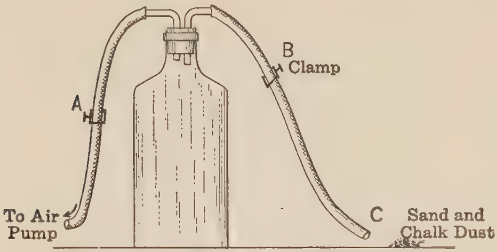


FIG. 261. — Principle of vacuum cleaning.

338. Vacuum cleaner tests. Three tests may be applied to a vacuum cleaner to determine if it will meet the requirements.

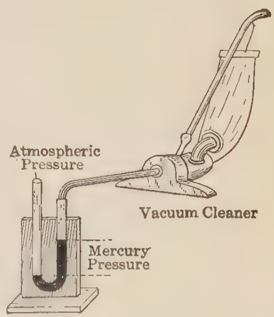


FIG. 262. — Testing the vacuum produced by a vacuum cleaner.

1. *Vacuum.* Under conditions of use, what vacuum is produced? Is it enough to clean well? Is it so great that it injures rugs and draperies?

2. *Capacity.* What volume of air does the machine draw per minute? The volume of air which passes through is

important in determining the size of cleaning tool which may be used and the speed of the air current.

3. *Efficiency.* What percentage of the dirt in a carpet does the cleaner remove?

339. Vacuum. The degree of vacuum which the machine is capable of developing is easily determined by plugging the entrance tube with a one-hole stopper, and connecting a water or a mercury manometer through the stopper. To measure the pressure under actual working conditions, one may make a hole in the pipe or tube for the manometer connection, then observe the pressure while the machine is in use with the regular attachments.

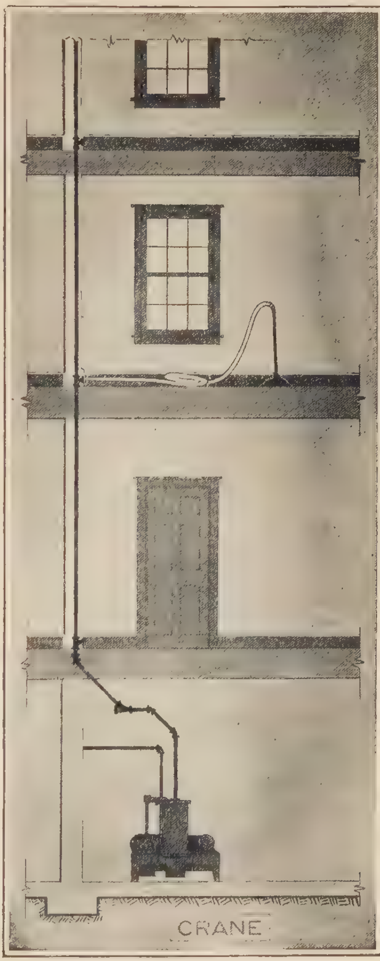


Fig. 263. — **A permanently installed** vacuum system.

340. Volume capacity. While it is the vacuum that loosens the dirt, it is the moving air that carries it away. In permanently installed plants there are some horizontal pipes, and unless there is a good volume of air to maintain a high speed its load of dirt will be dropped and

the pipe clogged. The size of tool used may to some extent influence the volume of air that will be drawn in, and the power of the machine will determine the volume of air that can be drawn through a given tool.

341. Efficiency tests. If it be desired to know just how efficient the machine is for cleaning purposes, a test may be made. Prepare a test rug, about 4 square yards in area, by first weighing it and then loading it with sand which has been screened through a 50-mesh screen. Work as much sand as possible into the rug, rubbing it in with the feet. Weigh the "loaded" rug. Clean for one or two periods of a minute each. Weigh the rug after each cleaning period. Calculate the percentage of sand removed in each period. The efficiency of the machine may thus be determined and the relative efficiency of different machines and of different tools compared. The following results, obtained by using different tools with the same machine, are of interest.*

Sand Test with Tool A (opening $\frac{5}{16}$ in. × 12 in.)

Trial	1	2	3
Vacuum in handle (inches of mercury)	1	$2\frac{1}{2}$	4
Cu. ft. of air per minute	30	45	50
Per cent of sand removed in 1 minute	45	61	50
Per cent of sand removed in 3 minutes	$73\frac{1}{2}$	84	77
Per cent of sand removed in 5 minutes	..	$94\frac{1}{2}$	97

Sand Test with Tool B (opening $\frac{1}{8}$ in. × 12 in.)

Trial	1	2
Vacuum at handle (inches of mercury)	2	$4\frac{1}{2}$
Cu. ft. of air per minute	$24\frac{1}{2}$	$39\frac{1}{2}$
Per cent of sand removed in 1 minute	48	54
Per cent of sand removed in 3 minutes	91	100
Per cent of sand removed in 4 minutes	100	..

* (Reported in Scientific American Supplement, Vol. 74, pp. 2 and 3.)

Tests with Tool C (opening $\frac{3}{4}$ in. × 10 in.)

Trial	Dust	Sand
Vacuum at the handle (inches of mercury)	$3\frac{1}{2}$	$3\frac{1}{2}$
Cu. ft. of air per minute	66	66
Per cent of dust or sand removed in 1 minute	40	68
Per cent of dust or sand removed in 2 minutes	60	82
Per cent of dust or sand removed in 3 minutes	90	100

Tool *A* had an opening $\frac{5}{16}$ inch by 12 inches; *B*, $\frac{1}{8}$ inch by 12 inches; and *C*, $\frac{3}{4}$ inch by 10 inches. Any one of the three tools will clean the rug. *B* would not be satisfactory for general use, since the $\frac{1}{8}$–inch aperture is too narrow for matches, paper, and much other floor litter. A vacuum of about $3\frac{1}{2}$ inches of mercury is essential for effective cleaning in a reasonable time. A greater vacuum than this will cause the carpet to cling so tightly to the tool that it is worn severely. In a pipe line, the velocity of air should not fall below 2500 feet per second, lest dust be deposited in the pipe. In the test noted above, tool *C* gave the best flow of air, indicated by the large volume per minute. Sand is more easily removed from a carpet than the rug dust. The test on an artificially sanded carpet gives a higher efficiency rating to the machine than is obtained when the test is made upon a dirty carpet not artificially prepared, as is shown by comparing the dust test and the sand test made with tool *C*.

342. The sewing machine. In the sewing machine one can, by a little observation, find levers, wheel and axle, inclined plane, and screw. These simple machines have been ingeniously arranged so that the one combined machine operated by one person will do the work of many persons who sew by hand. A machine can make three thousand stitches a minute.

FIG. 264. — Phantom view of a vacuum cleaner.

343. How the stitch is made. Phantom Fig. 265 shows the working parts of the head piece. The essentials for stitch making are the bobbin, bobbin-case, and hook, below the bed plate, and the needle and the thread take-up lever above. Thread is carried below the bed plate by the needle; the bobbin with under thread must then pass through a loop in the needle or upper thread. This may be accomplished by a vibrating shuttle, an oscillating shuttle, or a rotating hook. The different steps in making a stitch, when

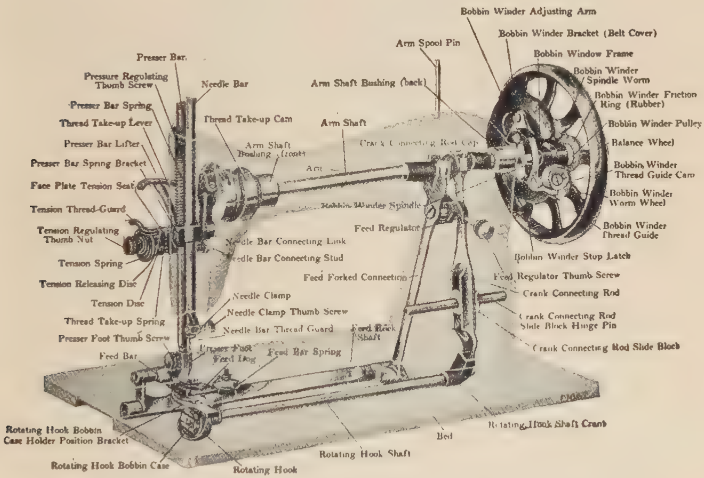


FIG. 265. — Mechanism of a rotary hook sewing machine.

the rotating hook is employed, are illustrated in Fig. 266. In step 1 the thread take-up lever is descending, thus loosening the thread at the needle. Just as the needle begins to rise, a loop of thread is formed. The point of the rotating hook now enters the loop of thread, which is carried around the stationary bobbin-case (step 2). In step 3 the hook has released the thread after having carried it around the under thread. The thread take-up lever now begins to draw the needle thread upward. Step 4 shows the completed stitch.

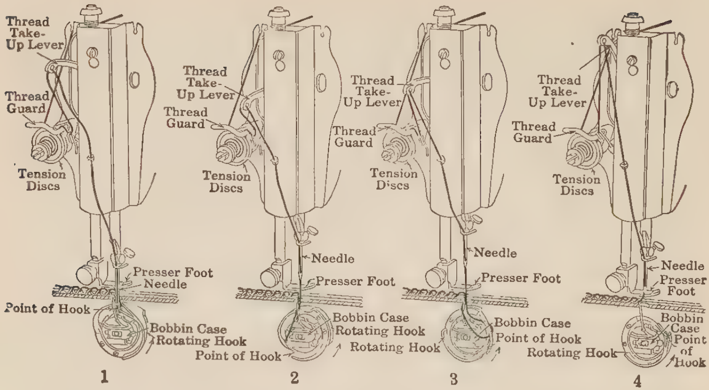


FIG. 266. — How the stitch is made.

POINT OF HOOK ENTERING LOOP OF NEEDLE THREAD

No. 1 shows the first stage in stitch formation. The thread leading to the needle is loosened, because the thread take-up lever has begun its descent; the needle, after having descended to its lowest point, has been slightly raised and a loop of thread is thus formed which is immediately entered by the point of the hook, which rotates in one direction around the stationary bobbin case.

LOOP OF NEEDLE THREAD ENCLOSING BOBBIN CASE

No. 2 shows the second stage. The loop of needle thread has been taken by the point of the hook and is being passed around the bobbin case containing the bobbin of under thread, sufficient enlargement of the loop having been permitted by the descent of the thread take-up lever.

UNDER THREAD ENCLOSED BY NEEDLE THREAD

No. 3 shows the third stage. The loop of needle thread has been cast off from the hook, the under thread has been enclosed by the needle thread, and the thread take-up lever is being raised to tighten the stitch.

STITCH COMPLETED

No. 4 shows the stitch completed. The thread take-up lever has been raised to its highest point, drawing the needle thread, together with the under thread, into the middle of the fabric, the two threads now being locked. The tension on the needle thread is regulated by the circular tension discs shown in the illustrations, and the tension on the under thread is regulated by a spring on the bobbin case.

The take-up lever has drawn the upper thread so that all slack is removed, and if the right tension is on the thread the upper and under threads of the lock stitch will be joined about half-way between the two surfaces of the materials which are being sewed.

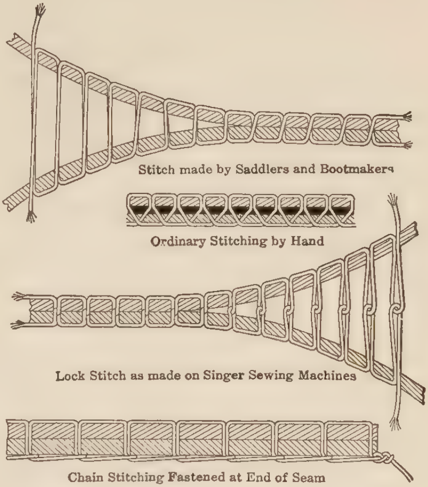


FIG. 267. — Types of stitches.

PROBLEMS

1. How much work is required to raise 10 gallons of water to an elevation of 20 ft.? (1 gal. water = 8 lbs.) If the efficiency of a pump used to lift this water is 50 per cent, how much work must be expended in pumping?

2. The weight on a boiler safety valve is 2 lbs. and is placed $1\frac{1}{2}$ ft. from the fulcrum. What steam pressure, acting at a distance of 2 inches from the fulcrum, will this balance?

3. The large wheel of an egg beater has 56 cogs, while the small wheel has but 7. How many times does the dasher revolve for each turn of the handle?

4. Make a diagram of a pulley, showing sheaves and number of ropes required to lift a weight of 400 lbs. by applying a force of 80 lbs.

5. A block and tackle has three strands of rope running to the movable block. In lifting a 300-lb. cake of ice 10 feet it is found that 600 ft.-lbs. of work are done against friction. What is the efficiency of the block and tackle as a machine? What force (effort) must be used to lift the ice with this machine?

SUMMARY

1. Machines make work less arduous, and yet, unless power driven, they cannot do the work for us. They do make it possible for us with small effort to overcome large

resistances, but our effort must be carried through a greater distance than that through which the resistance is overcome. In all machines, effort $\times$ distance effort is applied = resistance $\times$ distance through which it is overcome.

2. In the lever, the simplest of all machines, the effort $\times$ effort arm = resistance $\times$ resistance arm. Arm in each case is the perpendicular distance from the line of direction of the force to the fulcrum, or the point about which the lever has a tendency to turn.

3. The mechanical advantage of a lever is the ratio of the effort arm to the resistance arm. In some levers there is a speed advantage:

$$E \times E \text{ speed} = R \times R \text{ speed}$$

4. By considering the radii of wheel and axle as arms of a lever, all wheel and axle machines are resolved into a type of lever machine.

5. A fixed pulley gives no mechanical advantage. It is used in connection with movable pulleys and makes it possible to change the direction of the effort applied. The mechanical advantage of a movable pulley equals the number of ropes which come from the movable block.

6. With the inclined plane, a given force acting parallel to the incline will, if friction be neglected, lift a weight as many times itself as the incline is times the vertical distance. Or, expressed in formula:

Force $\times$ dist. (length of incline) = Wt. $\times$ dist. (vertical). The screw is a spiral inclined plane.

7. The efficiency of a machine is the ratio of the useful work done by a machine to the work expended upon it. Friction is the main cause of low efficiency in machines. Ball or roller bearings and lubrication are means of reducing friction.

8. The vacuum cleaner is a device for reducing the pressure, so that atmospheric pressure can push the dust and dirt into a container which holds the dirt but allows the air

to escape. The degree of vacuum determines how effectively the machine cleans, but a vacuum over $3\frac{1}{2}$ inches of mercury wears carpets severely and, by causing the cleaner to cling tightly, makes it difficult to move the machine over the carpet.

9. In the sewing machine, two threads are used. By means of a moving shuttle or hook, the under thread is looped around the upper thread to make each stitch. The advantage of the sewing machine lies in the saving of energy, in speed, and in the quality of work done.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. Archimedes, maker of early machines.
2. Machines of great power.
3. Evolution of the modern sewing machine.
4. Determine the mechanical advantage of some simple machines.

REFERENCE BOOKS

Allen. *Mechanical Devices in the Home.* The Manual Arts Press.
Lynde. *Physics of the Household.* The Macmillan Company.
Scott. *Home Labor-saving Devices.* J. B. Lippincott Company.
Smith. *Elements of Applied Physics.* McGraw-Hill Book Company.
Mechanics of the Sewing Machine. The Singer Sewing Machine Company.

CHAPTER XXII

THE AUTOMOBILE

344. The working parts of the automobile. The last quarter of a century has witnessed a very remarkable development in the automobile, which has come to be considered by many as an essential household machine. In spite of the large number of different makes and styles, automobiles are, with the exception of the relatively few electric and steam-driven cars, all alike in their fundamental features. The great majority of cars use gasoline for the motive power and require a gasoline engine. There are four important systems of working parts in every motor car: the running gear or chassis; the power plant; the transmission mechanism; and the electric system.

345. The chassis. The frame of a car is a vital part, as it serves to connect motive and transmission parts and to support them and the body. The axles are joined to the frame through springs. The wheels support the axles and receive power from the transmission system. Wheel controls, such as the steering gear and the brake devices, are all parts of the chassis. The frame is of chrome-nickel steel and the front axle is of vanadium steel. It is essential to use tough and unbreakable steel for many of the parts, for the sake of safety. In a horse-drawn vehicle the entire front axle turns in steering, but in the automobile a pivoted axle allows the wheels alone to turn instead of the entire axle. The turning is controlled by the steering wheel in the hands of the driver. The usual method of braking is to expand or tighten a brake band within or outside the brake drum, which is securely fastened to each rear wheel or to all four wheels. In some cars the brake drum

and band are on the propeller shaft, just back of the gear box.

346. The power plant. We may consider as belonging to the power plant the engine and those accessories which are essential to its proper working. This will include the gasoline supply system and the cooling system, in addition to the engine itself.

347. The gasoline supply system. A tank with a capacity of 10 to 20 gallons holds the gasoline supply. If the tank is at a higher level than the carburetor, gasoline will flow to the latter by gravity; but if the tank is at a

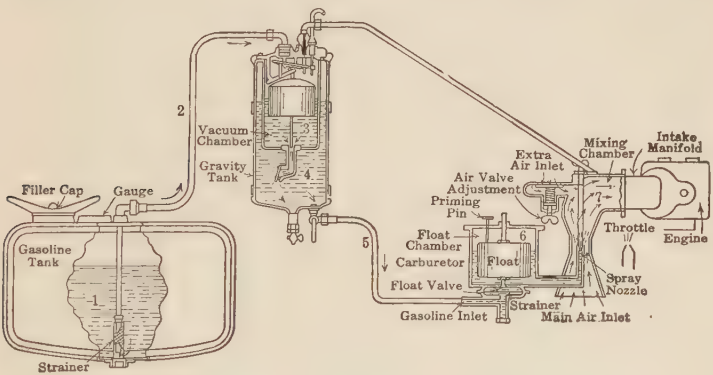


FIG. 268. — The gasoline system.

lower level, the gasoline must be brought to a supplementary tank, like the Stewart vacuum tank, from which it flows by gravity to the carburetor. In some systems, pressure is put upon the gasoline in the tank to force it into the supplementary tank.

348. The carburetor. An idea of the way the carburetor works may be gained from a study of Fig. 268. The main chamber holds a *float*, which rises as the gasoline level rises. At a certain level the float closes a valve and prevents more gasoline from entering until some has been used and the level drops. The float automatically keeps the gasoline

level in the jet tube about a tenth of an inch below the outlet so that it does not run out when the engine is still. But when the engine is running, suction produced by the piston removes pressure from the jet tube and a spray of gasoline issues from the tube into the intake manifold or mixing chamber. The priming pin is used to open the valve and flood the carburetor; this gives a richer mixture of gasoline, which is desirable in starting the engine in cold weather.

349. Gasoline engines. The action of the gasoline engine depends upon expanding gases. It differs from the hot-air engine in that heat is produced by burning a gas inside the cylinder, whereas, in the hot-air engine, the air in the cylinder is caused to expand by an external heat source. By means of the carburetor, gasoline is changed to a vapor. This vapor mixed with air makes the "charge" of gasoline and air which enters the engine cylinder.

The four-cycle gas engine is the one in common use. Power is applied to the piston every fourth stroke, or once in two revolutions of the flywheel. The operation of the engine is as follows:

1. On the first — the *suction* or *charging* — stroke, the inlet valve is open. The moving piston tends to produce a vacuum in the cylinder. Outside air-pressure forces a charge of mixed gasoline vapor and air into the cylinder.

2. In the second — the *compression* — stroke, both valves are closed and the returning piston presses the gas mixture into a small space, greatly increasing its pressure.

3. In the third — the *power* — stroke, an electric spark ignites the compressed gas mixture. An explosion follows, with resulting high temperature, and expansion of gases in consequence. Both valves are closed, and the piston is forced out under great pressure. This motion is communicated to the flywheel, which stores up energy in its momentum, to carry the piston through the next three strokes in which no power is applied.

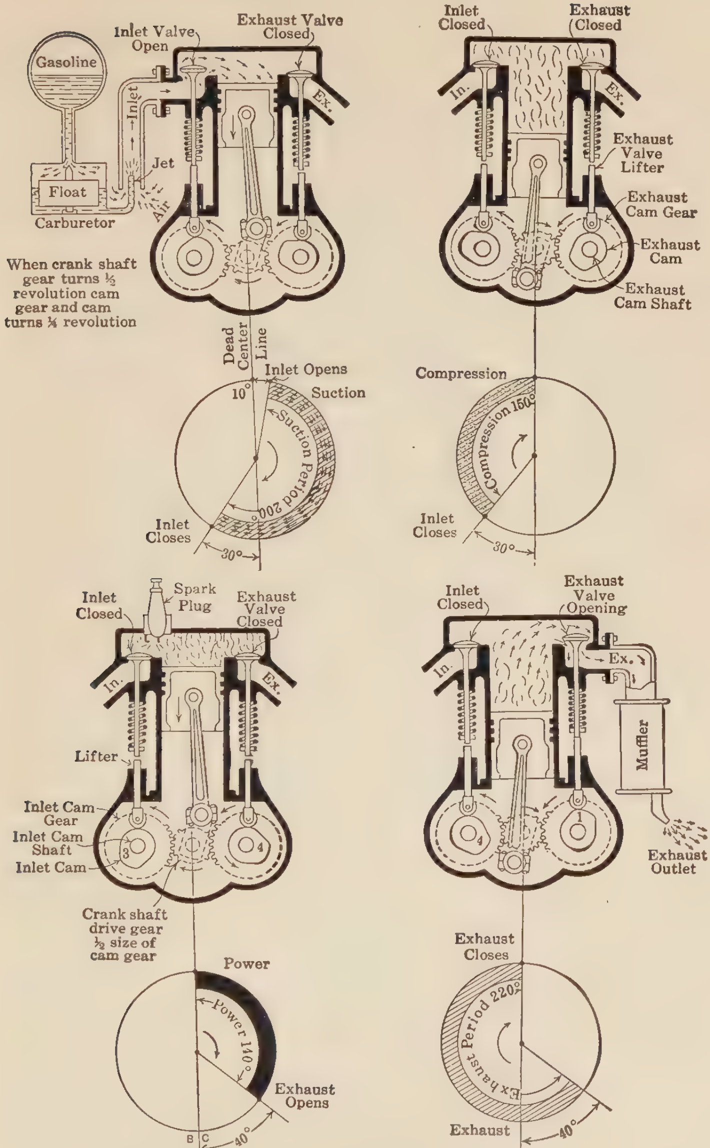


FIG. 269. — The four strokes of a four-cycle gasoline engine.

4. In the fourth — the *exhaust* — stroke, the inlet valve is closed and the outlet valve is open. The piston pushes the burned gases out of the cylinder, after which the whole series of strokes, beginning with No. 1, follows.

The exhaust gas makes a loud explosive noise if discharged directly into the air. The noise is greatly reduced if the exhaust is discharged through a *muffler*, which is a cylinder

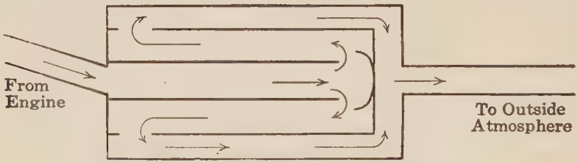


FIG. 270. — Construction of a muffler.

containing a number of chambers which allow the gases to expand more gradually before reaching the outside air.

350. Intake manifold. The intake manifold is the chamber in which the spray of gasoline from the jet tube of the carburetor becomes vapor and is mixed with air. It is joined to the inlet pipes of all the engine cylinders. The *throttle valve,* controlled by the foot accelerator and the hand lever on the steering wheel, is so placed in the manifold that the quantity of "charge" entering the engine can easily be controlled. A partial vacuum is produced here at each opening of a cylinder intake valve. By joining a pipe from the manifold through the vacuum tank to the gasoline supply tank, gasoline is brought to the vacuum tank to supply the carburetor. The relation of these devices can be understood better by referring to Fig. 268.

351. Number of cylinders. We have just seen what happens in one cylinder during a complete cycle. A similar cycle of strokes takes place in each cylinder. In a four-cylinder engine, four being the smallest number of cylinders which gives satisfactory service in an automobile, it is so arranged that the power strokes of the different cylin-

ders follow in succession rather than that two or more occur at the same time. This gives a more uniform application of power. In Fig. 271 you will observe four bands; each one represents the strokes of a single cylinder. The inner band is for cylinder 1; the next, 2; the next, 4; and the outer one is for cylinder 3. The black represents the power stroke.

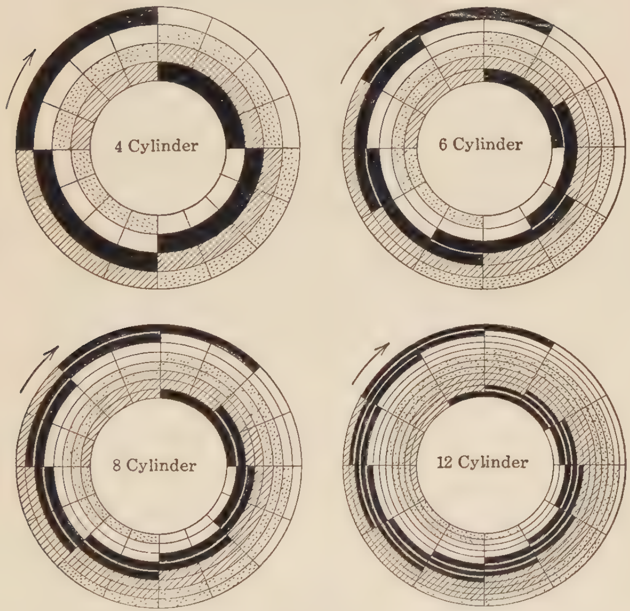


FIG. 271. — How an increase in the number of cylinders gives a more uniform application of power. The power strokes are represented in full black. Each circular band represents one cylinder.

There is practically a continuous power stroke, but there is no overlapping of power from any two cylinders. As the number of cylinders increases, there is more and more overlapping of the power strokes, which results in greater evenness in running and is a decided advantage in hill climbing and in running slowly in high gear in traffic.

352. Engine-cooling systems. Very high temperatures are developed by the burning gas in the cylinders — high enough to make the metal red hot unless the heat can be removed. Engines may be *air-cooled* or *water-cooled.* Cylinders of engines that are air-cooled are made in such form that they have a large radiating surface. This may be done by

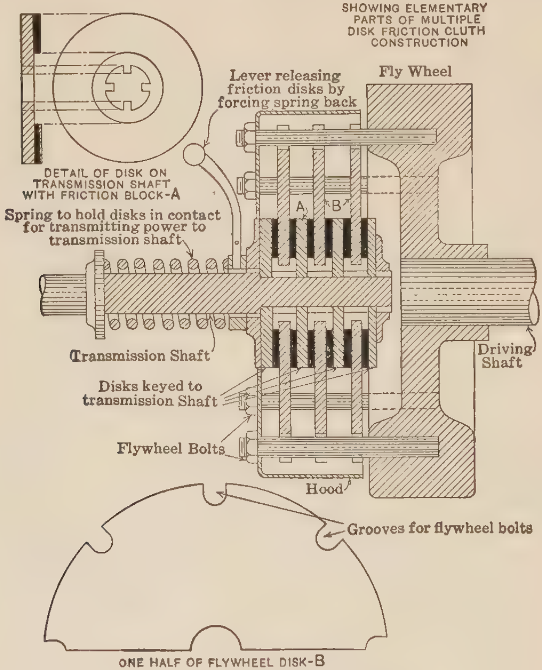


FIG. 272. — The disc clutch.

having flanges or by studding the surface with many projections. Much air is forced over these surfaces to remove the heat. Water-cooled engines have a water jacket surrounding the cylinders. This jacket is connected to both the top and the bottom of a radiator, where the hot water may be cooled both by radiation and by contact with cold air, which is made to flow over the surfaces by means of a

fan. In freezing weather, alcohol, or alcohol and glycerine are mixed with the water to prevent freezing.

353. The driving mechanism of the automobile. How is the power of the engine transmitted to the car? It is a complicated process involving a whole group of devices which are included in the transmission mechanism. They are: clutch, gears, universal joint, propeller shaft, differential, and rear axle. The rear axle turns the wheels, which, by means of the road resistance, carry the car forward.

354. Friction clutch. Of several types of clutches, the *friction clutch* is most used. The friction may be between plates, as in the *disc* clutch, or between the surfaces of a cone and a conical recess in the flywheel, as in the *cone* clutch.

In the cone clutch the flywheel of the engine has a conical recess in its rear side. A metal cone, faced with leather and attached to the driving shaft, fits into this recess. Foot pressure on the clutch pedal releases the cone so that the engine flywheel may revolve without moving the driving shaft. When the foot pressure is released a powerful spring presses the cone into the flywheel recess so firmly that the two revolve together. In the disc clutch the flywheel has attached to it a series of driving discs. An equal number of discs, attached to the driving shaft, are pressed against these by a spring.

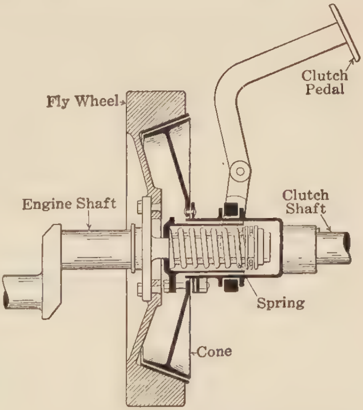


FIG. 273. — The cone clutch.

355. Power transmitted to wheels. By a system of interchanging gears, the driving shaft transmits motion to the propeller shaft. These gears are so arranged that different

forward speeds may be obtained or reverse motion produced. The propeller shaft turns a geared wheel in the *differential*, which transmits the motion to the wheels of the automobile. The differential contains gears so arranged that one rear wheel may turn independently of the other. This makes it possible, in moving around a curve, for the outside wheel,

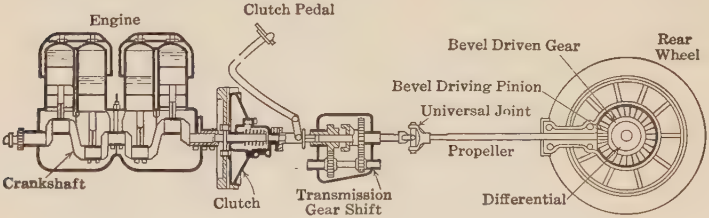


FIG. 274. — Transmission system. How power is carried from engine to wheel.

which goes a greater distance, to move faster than the inside wheel.

356. Electricity in the automobile. Electricity is used in the automobile to set off the charge in the engine, to light the lamps, to operate the starter, and to sound the horn. The source of current may be a generator, storage cells, or dry cells. One form of generator, the magneto, supplies high-tension electricity to ignite the charge in the engine cylinders. When a low-tension magneto is used the current must be stepped-up by a coil. Battery current through a step-up induction coil will give the necessary pressure to produce a good spark and is used in many makes of cars.

357. Generator and starter. Except for the very low-priced car, practically all cars have a generator or dynamo which is driven by the engine. The electricity is used to charge a storage battery. Since dynamos can also be operated as motors, when the engine is not running, current from the battery can be sent to the dynamo, which is thus made to act as a motor. By proper gear connection it will turn the

engine shaft and so start the engine. An automatic release throws it out of gear as soon as the engine starts, and it then becomes a dynamo again. In many cars a motor, separate from the dynamo, is installed to start the car.

358. Ignition systems. An electric spark within the engine cylinders is employed to cause the gas mixture to explode. High-potential electric current is required for this. The high-tension magneto is a dynamo with special wiring to produce current at sufficiently high potential to give the required spark. When storage battery, dry cell, low-tension dynamo, or magneto current is used, it must be stepped-up to a higher voltage by means of an induction coil.

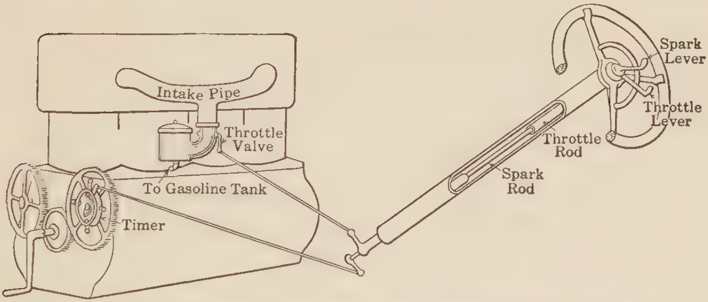


Fig. 275. — Throttle and spark lever control from the wheel.

Since the spark must be produced at the right time in each cylinder, an *automatic timing device* is required. This makes electrical contact to produce the spark. The spark can be advanced or retarded by the lever at the steering wheel. This lever acts on the timer to make the electrical contacts a little sooner (advanced) or a little later (retarded). For a heavy load, for hill climbing, and for starting, a slightly retarded spark is better. A spark too far advanced in ordinary running will in time injure the engine by excessive wearing of shaft and connecting rod bearings. When the spark is too far retarded, excessive heating of the engine occurs.

Each cylinder must receive its spark in its turn. It is necessary, therefore, to have a distributing device which sends the high-tension current to the cylinders in the order of firing. A cable with heavy rubber insulation goes from the distributor to each spark plug. Only one wire to each is needed, because the return is grounded. In a four-cylinder engine the firing order is 1, 2, 4, 3; cylinder 1 is the one forward, nearest the radiator. In a six-cylinder engine the firing order may be 1, 4, 2, 6, 3, 5, or 1, 5, 3, 6, 2, 4.

359. Electric lighting system. In lighting systems in which the storage battery is used, the voltage most com-

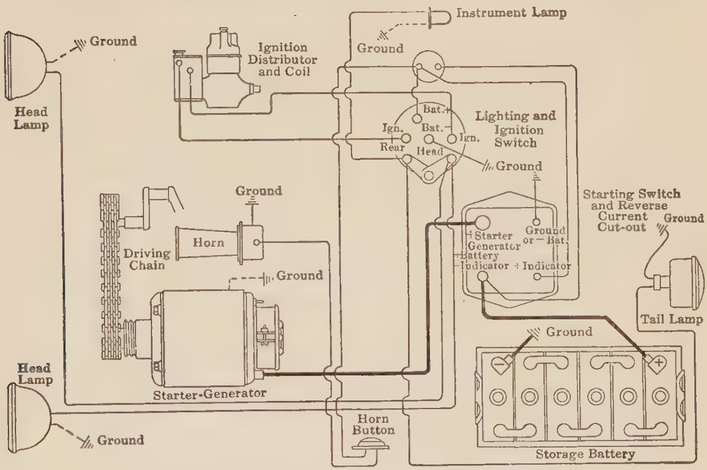


FIG. 276. — Lighting system in the Dodge.

monly used is 6 volts, though 12 volts are used in some cars. The low voltage allows the use of a larger and stronger filament in the lamp. There are two systems of wiring, *one-wire* and *two-wire*. In the one-wire system the metal framework of the car is used as a *ground*, and returns the current as does the second wire in the two-wire system. The lamps are joined in parallel but, if a rear *stop* light is used it

is well to have that in series with a 2-candlepower lamp on the dash, as then the driver can tell whether or not the rear light is on, since one will not be lighted without the other.

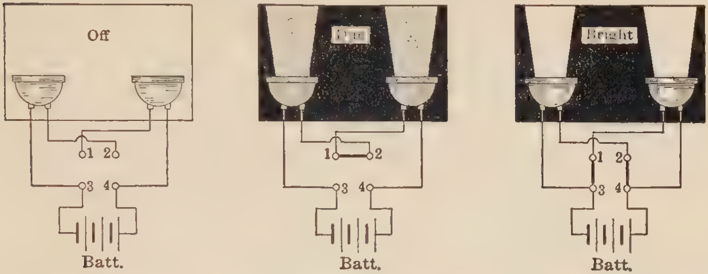


FIG. 277. — How the switch changes the current to vary the light intensity. Explain the diagrams.

360. Electric horn. Electric horns are made in two types. One, shown in Fig. 278, is operated on the principle of the electric bell, but with the moving armature causing vibration

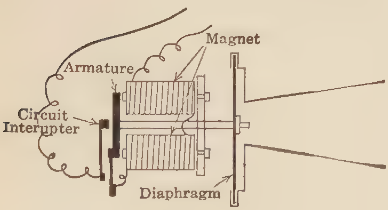


FIG. 278. — The electric vibrator horn.

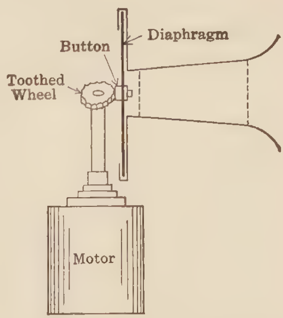


FIG. 279. — The electric motor horn.

in a diaphragm rather than striking a gong. The other has an electric motor which drives a toothed wheel against a button on the diaphragm, thus setting it into vibration, Fig. 279.

361. The storage battery. The common automobile storage battery is composed of 3 or 6 cells. Each cell contains lead plates in a solution of sulphuric acid. When the battery is charged, the negative plate is lead and the positive plate has a coating of lead peroxide on the surface and in the pores prepared to hold it. When the battery is supplying current for use, the reverse chemical action goes on, by which the lead peroxide reduces to a lower oxide. Each cell gives 2 volts. A 6-volt battery, then, must have 3 cells, and a 12-volt battery, 6 cells. The quantity of current the battery can give, after being charged, depends upon its size. Its capacity is indicated by the number of ampere-hours it will give. A 100-ampere-hour battery will give 100 amperes for 1 hour or 25 amperes for 4 hours. It is not well, however, to discharge a lead storage battery completely. The usual method of testing the condition of the battery is to determine the specific gravity of the acid solution. When fully charged, this has a specific gravity, of 1.28 to 1.3. The hydrometer scale is based upon pure water as 1000. Hence a fully charged battery shows by hydrometer test 1280 to 1300; half charged is 1215 and discharged or "empty" is 1140. The plates must be kept covered with liquid by adding distilled water or rain water at intervals. If the battery is idle, it should be charged every two weeks. This may be done by running the engine of the car for an hour,

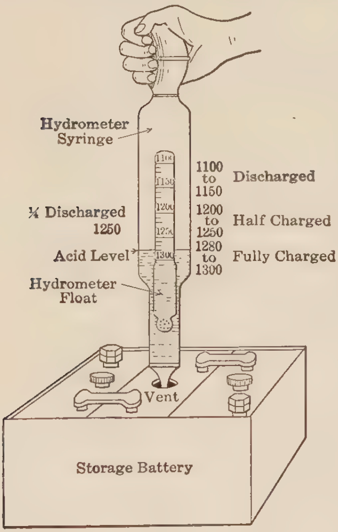


FIG. 280. — Testing the battery with a hydrometer.

at a speed equivalent to 20 miles an hour on the road. If the car is located where the engine cannot be run and it is not desired to remove the battery, one of the many small battery chargers should be used. This can be attached to the electric light socket and the battery charged over night every two weeks. Frequent recharging of an idle battery is necessary, as without this precaution it will run down and the plates become so coated with lead sulphate that it will be worthless. A fully charged battery will not freeze at $-80°$ F. At hydrometer test, 1200, it freezes only at $-16°$ F., but when discharged to 1140, it freezes at $-10°$ F.

362. "Pick-up" distance at night. The distance at which a person in front of the car can be seen at night depends upon the background, the color of his clothing, light glare, and the candlepower of the headlights. The headlights on many cars are so blinding that for a moment they completely destroy one's vision of objects ahead. Assuming a dark background and absence of glare, the curves shown in Fig. 281 indicate the candlepower required to pick up light, dark, and medium-colored objects ahead. Suppose a 21-candlepower lamp gives a beam candlepower of 50,000. A man dressed in dark blue is visible 900 feet away, one in medium color 1100 feet away, and one in white over 1500 feet away. If the adjustment of the lamp is poor or if the reflector surface is dusty or corroded, the beam candlepower may not be more than 15,000 candles. Under such conditions the pick-up distance is materially reduced. It must also be borne in mind that the other headlights facing the driver reduce the pick-up distance enormously.

363. Braking distances. Consideration of the pick-up distance leads us to another very vital question: "In what distance can the car be stopped?" If a person is seen 100 feet in front of the car and there is no opportunity to turn out, can the car be stopped in time? It all depends upon the road condition, the brakes, and the speed of the car. Tests which have been made give very valuable information on this

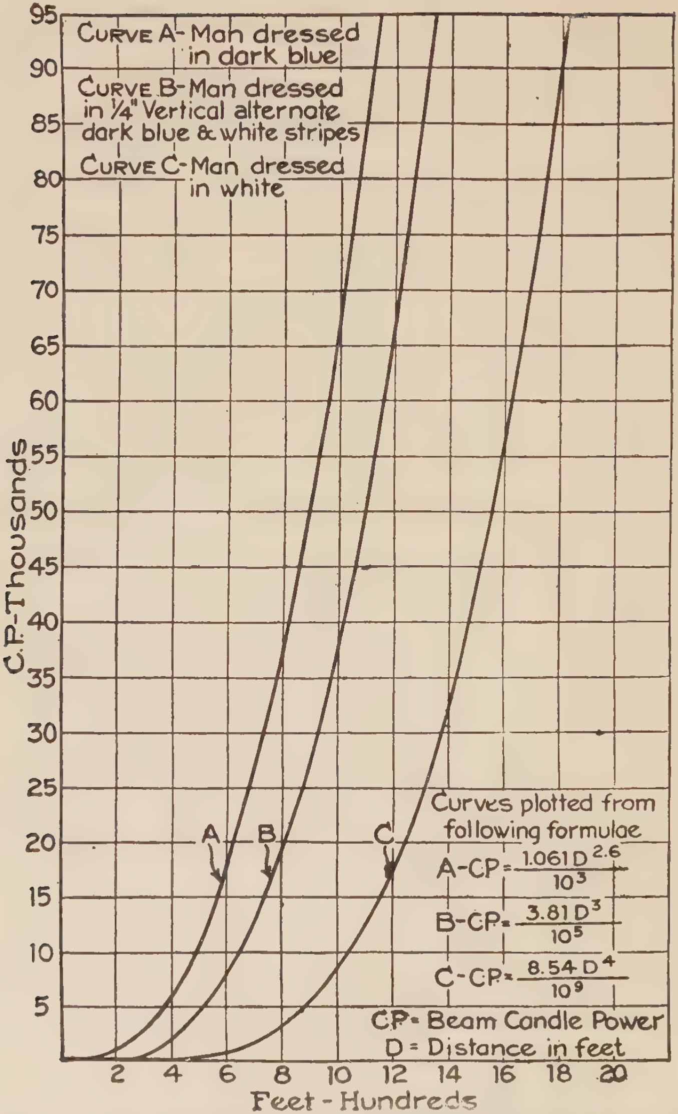


Fig. 281. — Pick-up distance for strength of light and for color of person's clothing.

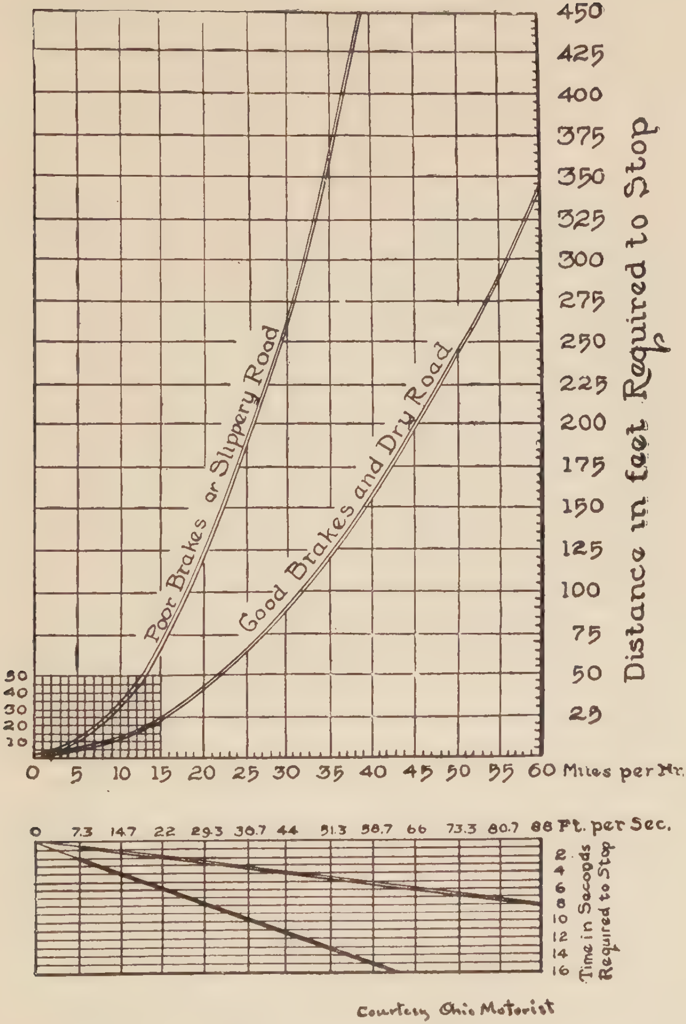


Fig. 282. — Braking distance for various conditions.

question. With poor brakes and a slippery road, a car going 20 miles per hour could not be stopped within a distance of 100 feet. With good brakes and a dry road, a car going 30 miles an hour could be stopped in less than 100 feet.

SUMMARY

1. The essential parts of an automobile are: chassis, body, power plant, transmission mechanism, and an electric system.

2. The chassis includes the frame support, springs, axles, steering gear, and brakes.

3. The supply of gasoline is stored in a tank, from which it is brought to the carburetor, where it is vaporized. The gasoline vapor mixes with air in the intake manifold, and then this mixture, known as the "charge," enters the engine cylinder, where it is ignited by means of an electric spark.

4. The gasoline engine commonly used in the automobile is of the four-cycle type. The four strokes in this cylinder are as follows: *suction*, by which a charge is drawn into the cylinder; *compression*, by which the charge is compressed into a small volume; *power*, by which the charge is exploded by an electric spark at the terminals of the spark plug; *exhaust*, by which the burned gases are removed from the cylinder.

5. With a four-cylinder engine the power strokes follow each other in rotation. With six or more cylinders there will be an overlapping of power strokes, and more even running will result.

6. To remove the heat resulting from the exploding gas mixture, air or water is circulated around the engine cylinders.

7. The power of the engine is communicated to the rear wheels through the clutch, gears, propeller shaft, differential, and rear axle.

8. The friction clutch, joining the engine shaft to the transmission mechanism, is usually of the cone type or the

disc type. In the cone clutch a conical member joined to the transmission is pressed into a conical recess of the flywheel by a powerful spring. In the disc clutch several discs on the transmission shaft are pressed by a spring against an equal number of discs attached to the inner surface of the flywheel.

9. The gear box holds gears so arranged that, through connection made by use of the gear-shift lever, different forward speeds and reverse motion are possible. When the lever is in neutral, no motion of the car results even though the engine is running and the clutch is in.

10. When a storage battery is used in a car, a generator is installed. This is run by the engine, and its current charges the storage battery. Sometimes this generator is also used as a motor to start the engine, or a separate motor may be used for this purpose.

11. The spark to explode the gas mixture in the engine can be produced only by an electric current at high pressure. This high voltage may be secured by means of an induction coil which receives in its primary circuit the current either from the battery or from a low-pressure magneto. The secondary wires go to the spark plugs.

12. The lights are connected to the battery through a switch on the dashboard. They must be of the right voltage for the battery. A 12-volt battery would burn out a 6-volt lamp. Lamps may be joined on either the one-wire or the two-wire system.

13. Electric horns are of two types, the vibrator, and the motor.

14. The lead-plate storage battery has negative plates of lead and positive plates coated with lead peroxide, in dilute sulphuric acid. Charging consists in sending a direct current into the battery to produce lead peroxide on the positive and to remove oxygen from the negative plate. When the charging current is disconnected, and the circuit is closed, this chemical action is reversed, and an electric current results.

The degree of charge is easily determined by means of a hydrometer.

15. The "pick-up" distance at night varies with the strength of the headlight and the color of the object.

16. Everyone ought to know the distance within which he can stop his car at different speeds. Brakes should be tested frequently to see that they are working properly.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. Development of the automobile industry in a quarter of a century.
2. Compare the advantages of six medium-priced cars.
3. Automobile accidents: the remedy.
4. Care of the battery.

REFERENCE BOOKS

Collins. *Keeping up with your Motor Car.* D. Appleton Company.

Dyke. *Motor Manual.* A. L. Dyke, St. Louis.

Good. *Laboratory Projects in Physics.* The Macmillan Company.

Hobbs, Elliott and Consoliver. *The Gasoline Automobile.* McGraw-Hill Book Company.

Pagé. *The Modern Gasoline Automobile.* The Norman W. Henley Publishing Company.

Pagé. *Storage Batteries Simplified.* The Norman W. Henley Publishing Company.

Caring for the Storage Battery. General Science Quarterly, November, 1921.

CHAPTER XXIII

HOUSEHOLD MEASUREMENTS

364. Weight. All bodies on or near the surface of the earth are attracted to the earth with a force which is proportional to the **mass** of the body, that is, the *quantity of matter in the body.* We speak of the force that draws a body toward the center of the earth as the *force of gravity.* The measure of this attractive force is called **weight.** The weight of a body varies slightly at different parts of the earth and is less if the body is carried high above or far below the surface of the earth. A given body weighs most on the surface of the earth, and at the poles. The point in a body at which we may regard all the pull of gravity, *i.e.*, the weight, as acting, is the **center of gravity** of the body.

Gravity is but a special case of the **law of universal gravitation,** namely, that *all bodies in the universe attract each other* with a force that varies inversely as the square of the distances between them and directly as the product of their masses.

The attraction between the earth and the bodies at its surface is mutual, but because of the enormous mass of the earth, we usually speak of the earth as pulling a falling body to it, though it is true that the earth is pulled toward the falling body to an infinitesimal extent.

365. Units of measure. In order to measure anything there must be some definite quantity, called a *unit,* with which to compare the quantity to be measured. Units for measuring length, volume, and mass are arbitrarily agreed upon. Certain units have been adopted as standard units of measure by the Government. The standard measures are

FIG. 283. — Household measuring devices. (*Bureau of Standards*).

all in charge of the National Bureau of Standards at Washington.

There are two systems of measurements which may be used legally in the United States:

The **English system,** employing such units as the pound, foot, quart, gallon, and bushel, is in common use in commerce; and

The **Metric system** is used in practically all scientific work, and to some extent in commerce.

366. Metric system of measurements. The simplicity of the metric system results from its being based on the decimal system. Comparison of similar units in the two systems shows the greater advantage of the metric system.

1 mile = 320 rods = 5280 feet = 63,360 inches.
1 kilometer = 1000 meters = 100,000 centimeters.

In the United States the value of money is measured by the decimal system, but our system of weights and measures is cumbersome, inconvenient, and time-wasting. Great Britain and the United States are almost the only countries that do not use the metric system today.

All metric units are based upon the unit of length, the **meter.** It was originally intended to make the meter one ten-millionth of the quadrant of the earth's meridian, but an error was made in measuring this meridian, and since the error was not discovered until after the meter had been adopted as a standard, it was decided not to change the length of the meter. The **standard meter** is the distance between two lines on a platinum bar preserved in Paris.

The unit of weight in the metric system is the **gram,** which is the weight of one cubic centimeter of pure water at 4° C. The unit of volume is the **liter,** which is the volume of 1000 grams (1 kilogram) of pure water at 4° C. A liter is slightly more than a quart.

Table XXII

METRIC–ENGLISH EQUIVALENTS

1 cm.	= 0.3937 in.	1 in.	= 2.54 cms.
1 m.	= 39.37 ins.	1 ft.	= 30.48 cms.
1 m.	= 3.28 ft.	1 ft.	= 3.05 m.
1 km.	= .621 miles	1 mi.	= 1.609 km.
1 gm.	= .035 oz. (avoir.)	1 oz.	= 28.35 gms.
1 kgm.	= 2.2 lbs. (avoir.)	1 lb.	= 453.6 gms.
1 sq. cm.	= .154 sq. in.	1 sq. in.	= 6.45 sq. cms.
1 cu. cm.	= .061 cu. in.	1 cu. in.	= 16.39 cu. cms.

1 liter = 1.0567 U. S. liquid quarts = 0.9081 U. S. dry quart = 61 cu. ins.

1 carat (for precious stones) = 200 milligrams

15 grains = 1 gm.

Table XXIII

MISCELLANEOUS VALUES

1 roll (wall paper) = 8 yds.	1 cu. ft. ice weighs 57.5 lbs.
1 bolt (cloth) = 40 yds.	30 cu. in. ice weigh 1 lb.
1 cu. ft. water weighs 62.4 lbs.	1 board foot = 144 cu. in.
1 cu. in. water weighs .036 lb.	1 gallon water weighs 8.34 lbs.

1 karat (fineness of gold) = $\frac{1}{24}$ gold by weight

1 cu. ft. air (at standard conditions) weighs .0817 lb.

1 cord = 128 cu. ft. cord wood is understood to be 4 ft. lengths

"Sawed" wood in some states is reckoned 110 cu. ft. to cord in tiers but 160 cu. ft. in a loose heap

Average Weight Anthracite Coal in *pounds per cu. ft.*

Color of Ash	Egg	Stove	Nut	Pea	Buckwheat
White	57.0	56.5	55.5	53.5	53.0
Red	53.0	52.5	52.0	51.0	50.5

367. Household balances. Two types of balances are in common use. Both of these are found in stores, and both are suitable for the home. The **beam balance,** which oper-

ates on the lever principle, is very reliable. It may have equal or unequal arms. In the more common form, the **equal-arm balance,** the pointer or index is brought to its proper position when the weights in the two pans are equal. The **steelyard,** once in almost universal use, is an example of an unequal-arm balance. The object to be weighed is hung from the hook or placed in a pan supported from the short arm, and is then "balanced" by sliding the small counter-weight provided along the long arm. In the practical instrument, the counter-weight balances the steelyard with suspended pan, when hung from the "zero" notch. The long arm is then graduated from this "zero," each notch being marked with the weight of the object on the pan or hook, which is balanced by hanging the counter-weight from that notch, so that no calculation is necessary.

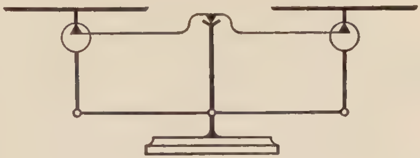


FIG. 284. — An equal-arm balance.

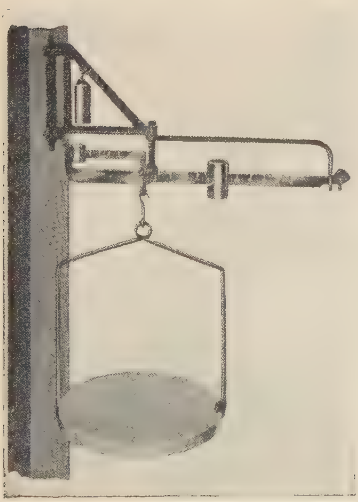


FIG. 285. — Suspension balance; steelyard type.

368. The spring balance. The principle on which the spring balance works is simply that the force required to elongate a coiled spring is, within the limits of elasticity, proportional to the amount of elongation. If 1 pound of force stretches a coiled spring $\frac{1}{2}$ inch, 2 pounds will stretch it 1 inch, and

6 pounds, 3 inches. It is thus an easy matter to make a scale over which a pointer moves so that the weight is registered while it is on the scale pan. Either one or two springs may be used with satisfactory results.

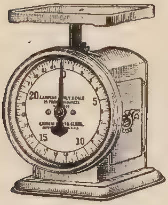


FIG. 286.—Household scale; spring type.

369. Measuring common commodities. Liquid commodities for household use may easily and accurately be measured by volume. This is not equally true of dry commodities, especially of coarse articles. Accurate measure of the amount of dry articles is possible only by weighing them. Several states now require that dry commodities be sold by weight; in other states they may either be measured or weighed. Greater uniformity in the law for different localities, and in the legal weight of cer-

FIG. 287. — These two measures have the same capacity, but the one with small diameter gives short measure by the amount overflowing on the table.

tain common volumes, as for example the bushel, the peck, etc., is greatly to be desired. Fraudulent dry measures are very easily prepared and used.

Table XXIV gives in convenient form the equivalents of common volume units frequently used in the household.

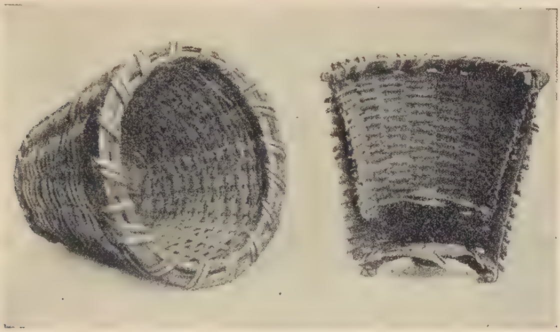


FIG. 288. — A reason why some purchases need to be checked by the purchaser.

TABLE XXIV

EQUIVALENTS OF THE COMMON CAPACITY UNITS USED IN THE KITCHEN

Units	Fluid Drams	Teaspoonfuls	Tablespoonfuls	Fluid Ounces	Gills ($\frac{1}{2}$ Cupfuls)	Cupfuls	Liquid Pints	Liquid Quarts
1 fluid dram equals.....	1	$\frac{3}{4}$	$\frac{1}{4}$	$\frac{1}{8}$	$\frac{1}{32}$	$\frac{1}{64}$	$\frac{1}{128}$	$\frac{1}{256}$
1 teaspoonful equals....	$1\frac{1}{3}$	1	$\frac{1}{3}$	$\frac{1}{6}$	$\frac{1}{24}$	$\frac{1}{48}$	$\frac{1}{96}$	$\frac{1}{192}$
1 tablespoonful equals..	4	3	1	$\frac{1}{2}$	$\frac{1}{8}$	$\frac{1}{16}$	$\frac{1}{32}$	$\frac{1}{64}$
1 fluid ounce equals....	8	6	2	1	$\frac{1}{4}$	$\frac{1}{8}$	$\frac{1}{16}$	$\frac{1}{32}$
1 gill ($\frac{1}{2}$ cupful) equals..	32	24	8	4	1	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{8}$
1 cupful equals.........	64	48	16	8	2	1	$\frac{1}{2}$	$\frac{1}{4}$
1 liquid pint equals....	128	96	32	16	4	2	1	$\frac{1}{2}$
1 liquid quart equals...	256	192	64	32	8	4	2	1

All measures are *level* full. From *Bureau of Standards*.

370. Density and specific gravity. The **density** of a substance is the *weight of a unit volume* of it. The density of water is 62.4 pounds per cubic foot or 8.34 pounds per gal-

lon. In metric units, water has a density of 1 gram per cubic centimeter. When densities are expressed in grams per cubic centimeter, the figures representing the densities also indicate the *relative weights* of unit volumes of the substance and water. For example, iron has a density of 7.5 grams per cubic centimeter; hence we know that, volume for volume, iron weighs 7.5 times as much as water, and we may calculate the weight of a cubic foot of iron by multiplying 62.4 by 7.5. The numerical ratio of the density of a substance to the density of water is the **specific gravity** of that substance. Thus, 7.5 is the *specific gravity* of iron, but the *density* of iron is 7.5 *grams per cubic centimeter.*

TABLE XXV

DENSITIES (APPROXIMATE AT 68° F.)

In grams per cc.

Solids		**Liquids — *Continued***	
Gold	19.3	Sirup (maple)	1.33
Lead	11.4	Milk	1.03
Copper	8.9	Cream (18% fat)	1.01
Iron	7.4–7.8	Cream (40% fat)	0.99
Aluminum	2.6	Gasoline	0.72
Cork	0.25	Kerosene	0.80
Glass	2.4–4.5	Alcohol	0.79
Human body	0.9–1.1	Olive oil	0.91
Butter	0.86	Mercury	13.6
Lard	0.92	Glycerine	1.26
Tallow	0.95	Sulphuric acid	1.84
		Storage battery acid (charged)	1.28
Liquids		Turpentine	0.87
Pure water	1.00		
Sea water	1.025	**Gases**	
Brine (5% salt)	1.035		
Brine (25% salt)	1.191	Air (dry)	0.00120
Cider vinegar	1.0114	Air (50% humidity)	0.00119

The specific gravity of cork is 0.25. Anything lighter than water will float, because the water buoys it up. A cubic foot of cork weighs 15.6 pounds, while a cubic foot of water weighs 62.4 pounds. It is therefore possible to load

a cubic foot of cork with 62.4 − 15.6, or 46.8 pounds, before it will sink in water. This explains the value of cork in life preservers.

371. Hydrometers. Advantage of the buoyant effect of liquids upon floating objects is taken in determining the specific gravity or density of liquids. A body that floats partially submerged in water will sink deeper if placed in a less dense (" lighter ") liquid, and rise higher out of the liquid in a denser (" heavier ") liquid. This happens because *a floating body always displaces a weight of the liquid equal to its own weight.* By arranging a suitable scale on the floating body by which to observe the level of the liquid, and by weighting the body so that it will always float in a fixed position, comparison of the density of any liquid with water as a standard may be made. Such special instruments are called **hydrometers.** One common type is shown in Fig. 280. The scale may be graduated to read specific gravity, per cent, or any arbitrary numbers.

The reading of the hydrometer should always be made with the eye on a level with the surface of the liquid. When great accuracy is desired, the test must be taken at a specified temperature, because the density of a liquid changes slightly with temperature. Can you tell why?

372. Meters. Our supplies of gas, electricity, and water are available at all times, usually in such quantities as we desire; and yet we do not store them on our premises as we do our coal, wood, oil, or gasoline. We may see the coal and oil measured, and a definite amount may be delivered to us to be stored for use; but gas, electricity, and water are measured only as they are being used. Meters for measuring gas and electricity are permanently installed and register the quantity that passes through them.

373. The gas meter. The gas meter receives the gas from the service pipe and records in cubic feet the quantity of gas that passes through into the consumer's pipe. Since the gas delivered is at a pressure above that of the atmosphere,

it is able to do work. Gas is therefore applied to operate the mechanism of the meter and it records its own volume. The gas meter is a gas-tight metal box, Fig. 289, having a gas entrance chamber *C* at the top where the slide valves are operated, and two small chambers, *A* and *B*, below. The chambers *A* and *B* are exactly alike. They each contain a metal diaphragm *D*, which is attached by means of flexible accordion-plaited sheep-skin to the fixed central partition *E*. The diaphragms *D* are thus free to move out or in, depending upon the direction of greatest pressure.

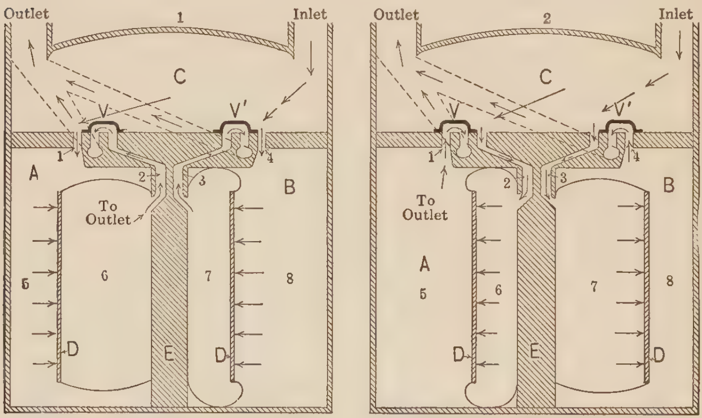


Fig. 289. — Section of the gas meter.

When the gas cock is open, gas flows through the meter and the following action takes place: Gas enters the chamber *C* through the inlet from the gas main. Gas passes through the ports 1 and 4 into the spaces 5 and 8. Ports 2 and 3 are now connected with the outlet pipe by means of the slide valves *V* and *V′*. Incoming gas is pressing against the diaphragms, and this greater pressure pushes the gas in 6 and 7 into the outlet pipes. Just as the diaphragms are moved to the left as far as they will go, the slide valves are moved over to connect 1 and 4 with the outlet pipes.

This permits the gas at the main pressure to come to 6 and 7 through the ports 2 and 3, thus pushing the diaphragms outward. The gas in 5 and 8 is now pushed through 1 and 4 into the outlet pipe. Since the diaphragms are moved a fixed distance each time, the volume of gas is accurately measured. The volume of the gas is recorded on an index which is connected with the diaphragms by levers. The diaphragms are attached to a long vertical rod and as they move out and in, they turn the rod in the upper part of the meter. This backward and forward rotary motion of the rod is transmitted by suitable lever arms to give rotation in one direction and, by means of wheels, records the amount of gas on the index. These same lever arms shift the slide valves. One valve closes the port one-fourth of a rotation ahead of the other in order to insure an even flow of gas. All this mechanism may be examined on a discarded meter which has been opened at the sides and top.

374. Reading the gas meter. The common index of the house meter has three recording dials on which the gas consumed is recorded. There is also a small dial at the top with a scale representing two or more cubic feet. This is used in testing the meter, and may be used to observe the amount of gas in an experiment when only a small amount of gas is used. Each pointer on the three large dials moves according to the arrangement of gear wheels in the works.

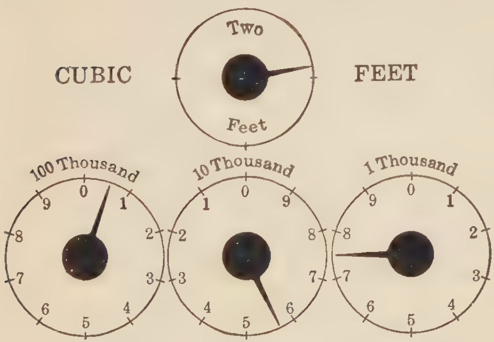


FIG. 290. — Gas-meter index.

When a new meter is installed, all of the dials read zero.

The pointer of the dial at the right moves one space for each hundred cubic feet of gas consumed. In the same time the middle pointer has moved one-tenth of a space, and the pointer at the left, one-hundredth of a space. When the right-hand pointer has made one complete revolution, it records 1000 cubic feet, and the middle pointer is on figure 1. When the middle pointer has made one complete revolution, the right-hand pointer has moved entirely around ten times, and the left-hand pointer has moved one space. The reading then would be 10,000 cubic feet. It will be observed that the middle pointer turns in a counter-clockwise direction, while the other two turn clockwise.

In reading a meter, begin at the left dial and read each dial in turn, recording the number that the pointer has last passed. This will be the number of hundred cubic feet of gas which the meter registers. The amount of gas used in a given period is found by subtracting the meter reading taken at the beginning from the reading taken at the end of the period.

Most beginners find it difficult to read the meter when one of the pointers is apparently just on one of the figures, but the pointer next to the right is somewhere between 8 and 10. When a pointer is around 8 or 9 it has not quite completed the circle and therefore the next pointer to the left cannot have traversed a complete space. Hence, in reading a pointer which is close to a figure, the reading of the pointer on the dial to the right must be considered before deciding what the reading is.

375. Prepayment meters. Prepayment meters differ from the common meter only in having an added device by which the gas is shut off after the quantity paid for has been used. These are usually fitted with a slot to receive a quarter of a dollar. After a quarter has been inserted the lever is turned. This acts upon a set of gears and advances a metal rod along a threaded screw. If the gas is off, this opens the pipe and also moves an indicator along a scale which can be seen on

the front of the meter. Several quarters may be inserted, one after another, the lever being turned each time. When gas passes through the meter, the same shaft that turns the wheels of the meter dials also turns the threaded screw upon which the metal rod was advanced. The turning screw pushes the metal rod back, and when it reaches the starting place it closes the gas inlet.

376. The electric meter. The electric kilowatt-hour meter, found in the home, is a device which uses a minute fraction of the current coming to the house to run a small motor. The revolving part of this motor operates the dial hands by means of interlocking gears. The amount of current passing through the motor is always in proportion to the amount of current being consumed in the house. It is therefore possible to use such a combination of gears that the dials will register the amount of electrical energy used.

The recording index of the house meter usually has four dials. The first dial (right) reads up to 10 kilowatt-hours and the fourth (left) to 1000 kilowatt-hours. The rule given for reading dials of the gas meter applies to reading the electric meter.

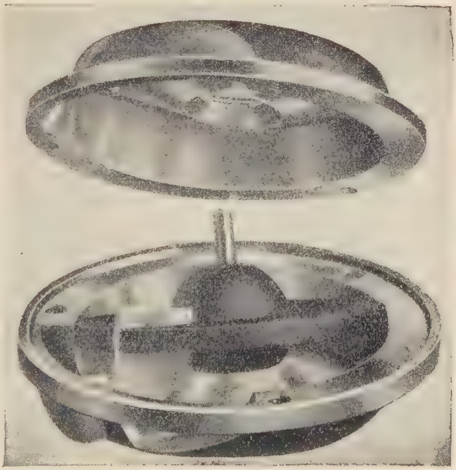


FIG. 291. — The measuring chamber of the water meter.

377. The water meter. The common house water meter is of the disc type. A flat, hard-rubber disc is attached at its center to a sphere whose axis is perpendicular to the disc.

On one side, the disc is slotted from its outer edge to the center sphere. This slot fits a partition which is between the inlet and outlet of the measuring chamber. The measuring chamber, Fig. 291, is the central part of a sphere. The axis of the disc is inclined some 20 degrees from the perpendicular. As water enters the chamber and presses, say, upon the upper surface of the disc, it keeps crowding its way farther and farther along, pushing the disc down until finally the under surface of the disc becomes exposed to the inlet. Then incoming water pushes upon the disc, forcing all the water on the other side of the disc out through the outlet pipe. The quantity of water admitted each time just fills this space and, by proper connection of the rotating axis with geared wheels, the quantity of water which is passed through the meter is recorded. Such ratio of gears is used that the dials, Fig. 292, record gallons of water. The reading of the meter is not different in principle from that of the gas meter or the electric meter.

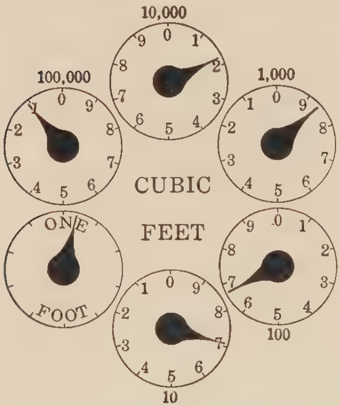
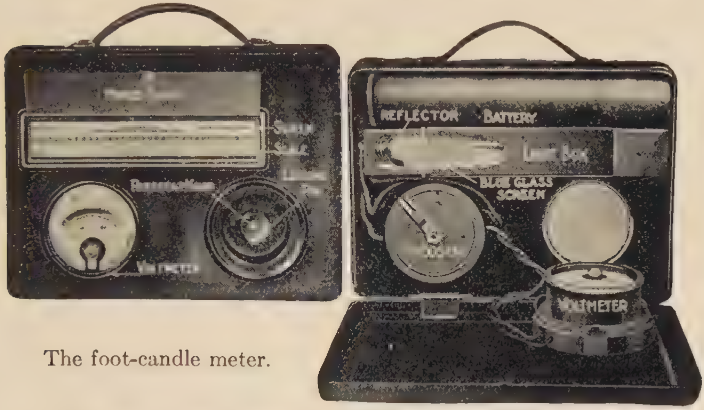


Fig. 292. — Water-meter index.

378. Measurement of illumination. The important thing about light measurement is to know how strong the light is at a given place where it is being used. For this purpose the **foot-candle meter,** Fig. 293, is used. With this instrument the intensity of the light in foot-candles can be read instantly. The instrument works on the principle of comparison. If a piece of cardboard having a small opening, over which is pasted a piece of white tissue paper, is placed between the eye and a source of light, the tissue paper appears brighter than the white cardboard. If, however, the

eye and the source of light are on the same side of the cardboard, the spot appears darker than the white cardboard.



The foot-candle meter.

FIG. 293. — Front view at left and rear view opened at right.

FIG. 294. — Using the foot-candle meter to determine the illumination on the desk and on the wall.

If the illumination on both sides is the same, the tissue paper and the cardboard appear to be of the same brightness.

This principle is applied in the foot-candle meter. A standard electric lamp illuminates the under side of a card with tissue-covered spots at varying distances from the lamp. If the meter is placed on your desk, light that would illuminate the desk falls upon it, and spots at one end of the screen are lighter and those at the other end are darker than the surrounding screen. Where the spot and screen appear alike, read the scale in foot-candle units.

379. Early measurement of time. The first measurement of time was a rough division of the day by the position of the sun and the length and position of shadows. Then came the **sundial,** which was in use in China as early as 1100 B.C. **Water clocks** were in use about the fifth century B.C. These had one decided advantage over the sundial in that they could be used at all times, while the sundial was of no value except when the sun was shining. The **hour glass** works on much the same principle as the water clock, but falling sand replaces the water. The hour glass was first used in the eighth century A.D. It still finds use as a "three minute" glass to time the "boiling" of an egg. **Clocks** are traced back to the fourteenth century, although it was much later that they became cheap enough for common use.

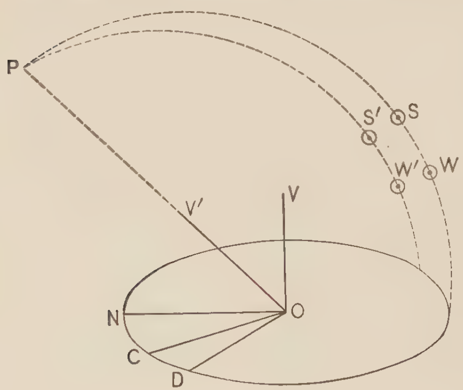


FIG. 295. — The style of the sundial ($v'o$) must point towards the North Star.

380. The sundial. Sundials are now made for their artistic value rather than their usefulness. A study of Fig. 295 will show you why the *style* of the sundial must be inclined a number of

degrees equal to the latitude of the place where the dial is to be used. OP is a line parallel to the earth's axis, P represents the polar star, S and W represent the midday sun in summer and in winter respectively. S' and W' represent the sun at 10 A.M. in summer and in winter. If the style of the dial were vertical (VO), the summer and winter sun would cast a shadow due north in both cases, but the winter sun at 10 o'clock would cast a shadow OC and the summer sun OD. If, however, the style is inclined so that its upper edge points towards the North Star ($V'O$), the position of the shadow cast by the style at any given hour will be the same during the entire year. As sun time may be fast or slow in comparison to our clocks, which register mean solar time, the sundial seldom gives us correct time. Its greatest variation from mean solar time is about sixteen minutes.

381. Household clocks. Two types of clocks are in use today, the **pendulum type** and the **balance-wheel type.** The power to drive the wheels is derived from the *mainspring,* although in some old-fashioned clocks weights are used as they were in the earlier clocks. The pendulum clock must be kept upright. This is not necessary with the balance-wheel clock or the watch, which is of the same type. The purpose of the pendulum or the balance-wheel is to obtain uniform speed. Working with these is a very important device known as the escapement. It is through this that the pendulum or the balance wheel controls the speed of the train of wheels in the works of the clock. It is also through these that the mainspring gives the force which keeps the pendulum and the balance-wheel from stopping.

382. The simple pendulum. The simplest pendulum we can devise consists of a weight suspended by a fine thread. At rest it hangs vertical. If pulled aside and released, it swings back and forth, the momentum gained in falling from its elevated position at one side to its lowest position being

sufficient, were there no friction, to raise it to the same elevation on the other side. Even with friction it will con-

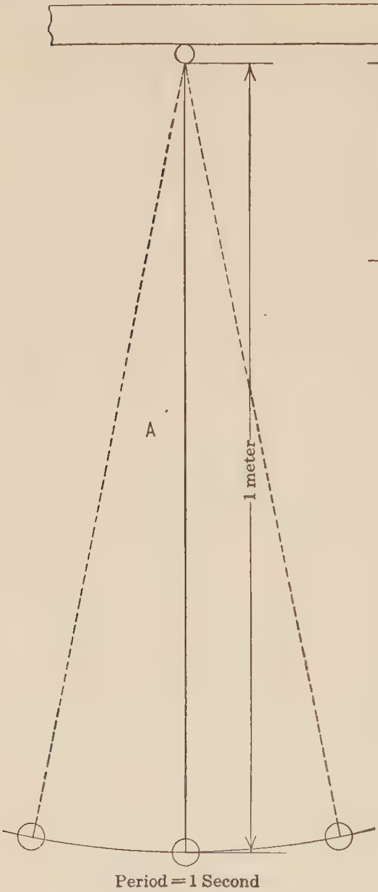


Fig. 296. — Pendulums.

tinue to vibrate for a long time. Galileo was the first to observe that each swing of a swinging body consumed the same period of time. He timed the swinging lamps in the cathedral of Pisa, using his own pulse to measure the duration of the swing. The application of this discovery to time-keeping devices is at once apparent. Another fact easily demonstrated is that the time of the swing, called the **period** of the pendulum, *varies as the square root of the length of the pendulum.* A pendulum one meter long makes one vibration in one second, but a pendulum one-fourth of a meter long has a period of one half second.

$$P_a : P_b :: \sqrt{l_a} : \sqrt{l_b}$$

therefore $$1 : \tfrac{1}{2} :: \sqrt{1} : \sqrt{\tfrac{1}{4}}$$

383. The pendulum clock. The really successful clock came about the year 1700. It resulted from combining the falling weight for power, the swinging pendulum (Galileo's discovery) for regularity of motion, and the *dead-beat escapement* invented by George Graham, to prevent the pendulum from coming to rest. The escapement consists of a toothed wheel W and a rocker arm ACB, Fig. 297. The inside of pallet A and the outside of pallet B coincide with the arc of the circle of which C is the center. The falling weight or, in modern clocks, the spring, causes the wheel W to turn.

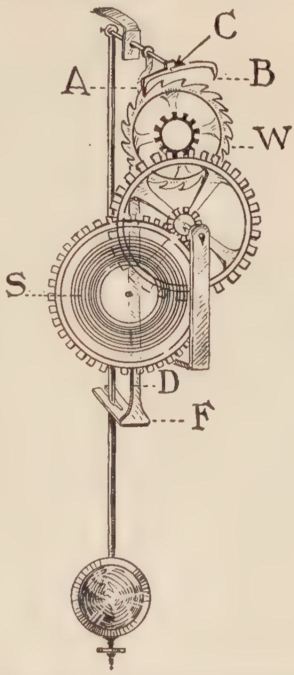


FIG. 297. — How the escapement and pendulum work together.

The pendulum is usually suspended by a thin flat spring. At some place along the pendulum rod a contact is made with the pronged fork F, which is joined to the escapement rocker C by the rod D. As the pendulum swings, rod D swings and turns the rocker so that the projections at its ends alternately catch in the teeth of the escapement wheel W. This is one of a train of wheels driven by the mainspring or weights. The rocker allows but one cog of the wheel to pass during a complete vibration of the pendulum. For the wheel to make one revolution, the pendulum must swing back and forth as many times as there are cogs in the wheel.

As each cog escapes from the rocker, a slight impulse is given to it and is communicated to the pendulum, which would otherwise soon cease to vibrate. By the proper relation of the cogs on the various wheels in the clock, the two different speeds for the hour hand and minute hand are secured.

384. The balance-wheel. The balance-wheel with spring is another device for securing vibrating motion, equally timed as in the pendulum. Its advantage lies in its compactness; without it we could hardly have watches. In hot weather the wheel increases in diameter and changes the period of vibration. To compensate for changes in temperature, the rim of the balance-wheel is usually composed of two parts. One end of each part is joined to a spoke of the wheel, and another end is left free. Each part of the rim is a compound bar so made that as it expands the free ends of the rim bend inward just enough to balance the expansion of the fixed ends. The balance-wheel of a watch makes 18,000 vibrations an hour and moves a distance of 18 miles a day.

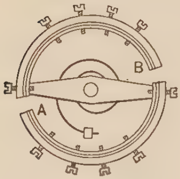


Fig. 298. — Balance wheel.

385. Compensating pendulums. When the temperature rises and the ordinary pendulum lengthens through expansion, an adjustment may be made to raise the bob. A better plan is that of using a compensating pendulum which is so devised that the center of gravity of the bob is always the same distance from the point of support of the pendulum.

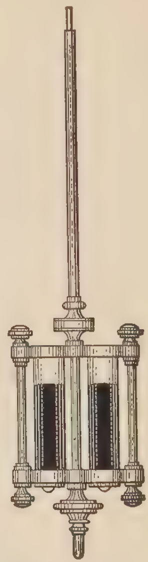


Fig. 299. — Compensating mercury pendulum.

One form of the compensating pendulum is the **mercury pendulum,** in which, as the pendulum grows longer, the expanding mercury rises enough to compensate for its lengthening. This is shown in Fig. 299.

Another form is known as the **gridiron pendulum.** The bob is suspended from a combination of steel and brass rods so arranged that the expanding steel tends to lower, while the expanding brass tends to raise, the bob. Such proportions are used that the length of the pendulum remains constant in spite of temperature changes.

386. The metronome. This is a form of loud-ticking clock without face or hands. The time interval is communicated either by sound or sight. The pendulum of the metronome is unlike the usual clock pendulum in that it has a sliding bob above its point of suspension. By sliding the bob higher, the metronome is made to beat slower time, and by lowering it, to go faster. The chief use of the metronome is in marking time in music, though it is also useful in marking time for experimental purposes, when it would be inconvenient to look at the hands of a watch.

SUMMARY

1. The different commodities used in the household require a variety of units of measure. Volume is the space a body occupies. Weight is the measure of gravity.

2. There are two systems of measurement: the English, used commonly in England and the United States; and the metric, used commonly in all other countries and everywhere in scientific work.

3. A household balance is useful in checking up small purchases. The beam balance works on the lever principle, and the spring balance on the principle that a coiled spring stretches equally for equal weight.

4. Density is the weight of a volume of a substance, and specific gravity is the ratio of the density of a body to the density of water. The hydrometer is a convenient instrument for measuring the specific gravity of liquids.

5. The pressure of gas in the mains supplies the necessary force for operating a gas meter, by means of which the

gas is measured and the quantity recorded on the meter index.

6. The kilowatt-hour meter measures electricity by using a small fraction of the current to run a motor for making the record.

7. Water is measured in the disc meter by means of a slotted disc which allows a measured quantity of water, alternately above it and below it, to pass from the meter inlet to the outlet. The moving axis operates the recording mechanism.

8. Illumination at any place is easily measured by means of the foot-candle meter. This utilizes the principle of comparison of reflected and transmitted light. A standard light is used in the instrument to light the under side of the screen.

9. The sundial, which dates back about three thousand years, was once a common means of marking time during the day, but was of no use except on sunny days.

10. The pendulum clock makes use of the fact that each swing of a pendulum consumes an equal period of time. By connecting a pendulum to the escapement rocker of the clock works, uniform speed of the wheels is obtained. Equal-timed vibration may also be secured by means of the balance-wheel.

11. The motive power in clocks is usually a coiled spring. In some clocks it is an elevated weight.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. Legal weights and measures in the state.
2. Advantages and disadvantages of having the metric system made legal and compulsory in the United States.
3. Learn to read meters.
4. Study the periods of pendulums experimentally.

REFERENCE BOOKS

Butler. *Household Physics.* Whitcomb and Barrows.
Rensselaer. *A Manual of Home Making.* The Macmillan Company.
Measurements for the Household. United States Bureau of Standards.

CHAPTER XXIV

SOUND IN THE HOME

387. What is sound? If we bring a pith ball, held by a thread, to the prong of a sounding tuning fork, the ball will be violently forced away. If we touch the surface of water with the end of the sounding prong, a spray of water will result. If a wire be attached to one prong of a fork, and, when the fork is sounded, we draw a smoked glass under it, with the wire resting lightly on the smoked surface, a wavy line is produced. None of these results occur if the tests are made when the fork is quiet. These experiments show that the fork, when producing sound, is vibrating. The prongs move back and forth with great rapidity. By using a pendulum to mark off a known interval of time on the smoked glass at the same time that the fork is making a record of its vibrations, it is possible to determine the number of vibrations per second, or the vibration **frequency.**

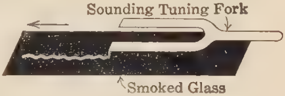


FIG. 300. — Proof that a sounding tuning fork is vibrating.

It is said that a frequency of 16 vibrations per second will produce the sensation of sound in some persons, while in others vibrations lower than 30 are not heard as sound. From these lower limits, vibrations up to 40,000 or more per second are heard as sound by most people. Some ears do not hear vibrations above 38,000 or 39,000, while some claim to hear sounds produced by 50,000 vibrations per second. The $7\frac{1}{3}$ octave piano has a range from $27\frac{1}{2}$ vibrations to 4600 vibrations.

Sound is that form of vibratory motion which is capable of affecting our sense of hearing.

388. How sound travels. Experiment shows that sound will not travel in a vacuum. Matter is necessary to transmit the sound wave. When a body is sounding in air, we may be reasonably sure that the air is carrying the sound. We also know that sound travels in every direction from its source; otherwise it could not be heard in all directions. The wave must therefore be spherical in form.

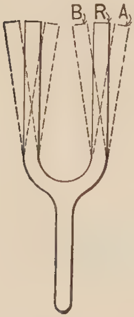


Fig. 301. — Motion of the prongs of a sounding tuning fork.

To understand just what this wave is, let us consider a portion of the entire wave, just that portion in the air between a sounding tuning fork and the ear. The air, as we know, is composed of molecules separated by spaces. During vibration, the fork moves from its position of rest R, Fig. 301, to the right A, back to R, continuing to the left to B, then back to R and to B and so on. When the fork moves from either B or R to A, it strikes the molecules of air a blow which pushes them forward, crowding them nearer together than they were. This condensation of air molecules continues as a *wave motion*. The molecules of air move forward a short distance, and give their energy to other molecules, which in turn pass it on to still others. Thus there is no stream of air molecules as a wind passing from the fork to the ear, but only a wave. When the fork goes back from A to B, it leaves a space behind it with fewer molecules than are in normal air. This rarefied space always follows a condensation. Thus a complete *sound wave is made up of a condensation and a rarefaction.* A body producing a sound due to 256 vibrations per second will send out 256 condensations and rarefactions every second. These are transmitted by the air.

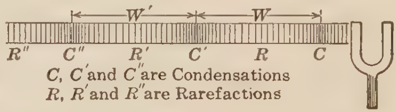


Fig. 302. — Sound waves. W represents the wave length.

Sound will travel through solids and liquids even better

than through gases. If you hold your ear near a steel rail and someone a distance away strikes the rail a hard blow, you will hear the sound twice, first through the rail and a little later through the air. At the temperature of freezing water, sound travels 1090 feet per second, but in water it travels four times as fast as this, and in steel fourteen times as fast. Sound travels faster in warm air than in cold air. Sound waves may be reflected, and when the reflecting surface is at least 60 feet away, the reflected sound may be heard as an **echo.**

389. Loudness of sound. There are three factors which determine the loudness of a sound in air. We all know that *distance* is one factor. Since sound travels in spherical waves which are ever growing larger, the energy is covering a larger and larger space and so must be weaker in any one place. The surface of a tuning fork is small, and for that reason it is unable to move a large body of air. If, however, the end of the fork handle is pressed firmly against the table top, it forces the *larger surface* into vibration, with the result that a larger air surface is affected and a louder sound produced. The third factor is the energy of vibration, or *amplitude*. When the prongs of the fork are plucked lightly, a soft sound is heard, but when struck sharply so that they vibrate through a greater space, they produce a much louder sound.

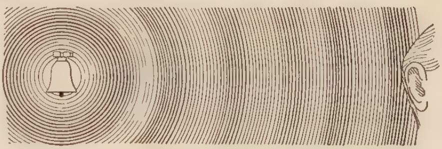


FIG. 303. — Sound waves travel in spherical waves.

390. Sympathetic vibrations. It frequently happens that when a certain note on the piano is struck, some object in the room will be set into vibration and produce sound. The sounding piano wire will also set a violin string of the same pitch (same number of vibrations) into vibration if it is near. This vibration of one body, caused by the vibration of a

neighboring body of the same pitch, is called *sympathetic vibration.* It may be demonstrated by having two mounted tuning forks of the same pitch near each other. When one of them is set into vibration and quickly stopped, the second fork will be found to be giving out sound.

391. Interference and reinforcement. Sound waves may unite so that one neutralizes the effect of the other, or so as to increase the sound, according to the phases of the waves which come together. If two waves of the same frequency come together in opposite phase, that is, if the condensation of one meets the rarefaction of the other, both being of the same amplitude, silence will result, as illustrated in Fig. 304. This is called *interference.* But if these two waves combine

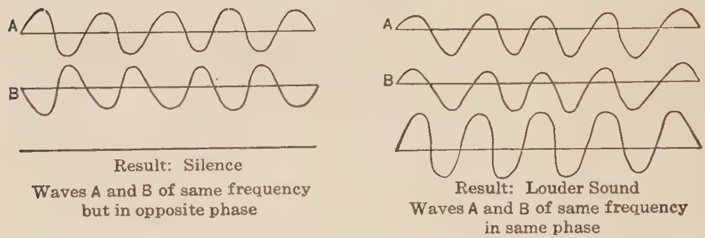


Fig. 304. — Interference and reinforcement of sound waves.

like phases, that is, if the condensation of one unites with the condensation of the other and their rarefactions combine also, then the loudness of the sound will be increased, or we may say there is *reinforcement* of sound, Fig. 304. If two sound waves differ slightly in frequency, some of the condensations of one will unite with the condensations of the other and reinforce the sound, but other condensations of one will unite with rarefactions of the other and reduce, if they do not destroy, the sound. As a result there will be periodic increases and decreases in sound, known as **beats.** Two notes on the piano, whose vibration rates differ from 10 to 40, will, if sounded together, produce unpleasant discord because of the beats which result. When the number of beats is as high as 60 the discord

ceases, because the beats are not distinguishable as individual sounds, but rather as one harmonious sound.

392. Music. Musical sounds produce a pleasing effect upon the ear, while noise is a combination of sounds which is unpleasant to the ear. To illustrate this, try the following experiment: A metal disc having two rows of holes, one equally spaced, the other irregularly spaced, is rotated rapidly and a current of air blown into the holes. Each puff of air through a hole gives the same effect on the air which it strikes as a vibrating body; hence sound results, as it does in the familiar siren whistles. It is found that when these impulses are regular, a musical sound is produced, but when the impulses are irregular, noise results.

Musical sounds may vary in their number of vibrations, or **pitch.** Sounds resulting from few vibrations per second have a low pitch, and those having many vibrations have a high pitch. Not all sound which is rhythmic and has a definite pitch is musical to all people. For example, the monotonous tom-tom and the cries that accompany the Indian war dance are not music to us, though they may be to the Indian.

393. Harmony. When sounds due to frequencies which bear a simple ratio to each other act together, the result is *harmony.* For example, if three bodies sound together, and one of them gives 256 vibrations per second, the second 320, and the third 384, harmony will result, for their vibration ratio is simple, being $4:5:6$. Any combination of three notes having this same ratio is known as a *major triad* or *major chord.*

394. Diatonic scale. If we use the major triad suggested and then use the note of 384 vibrations as the starting point for a second triad, we shall have, for the second triad, a vibration ratio of $384:480:576$. A third triad ending with the octave above 256 or 512 gives $341\frac{1}{3}:426\frac{2}{3}:512$. By arranging these frequencies in numerical order we have the *major diatonic scale.*

Middle C of the piano scale is considered by the physicists to be 256 vibrations, but in music it is usually a different number. In the **international pitch** middle C is 261, while in **concert pitch** it is 274 vibrations. The ratios for the different notes,

Staff									
Name	do	re	mi	fa	sol	la	ti	dó	ré
Vibration ratio	1	9/8	5/4	4/3	3/2	5/3	15/8	2	18/8
Vibration frequency (Physical)	256	288	320	341.3	384	426.6	480	512	576
Letter	C	D	E	F	G	A	B	C′	D′
Three triads	4		5		6				
					4		5		6
				4		5		6	

FIG. 305. — The musical scale.

however, are the same as suggested above. Intermediate tones are produced by adding notes between C and D, D and E, F and G, G and A, and A and B. These are the sharps and flats the black keys on the keyboard. The octave contains twelve notes, with a range as from middle C to the C above.

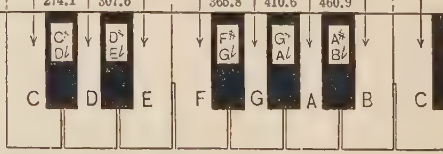
Perfect scale of Key of C	256.0		288.0		320.0	341.3		384.0		426.6		480.0	512.0
Tempered " " " " "	256.0		287.3		322.5	341.7		383.6		430.5		483.3	512.0
Tempered international pitch for piano. White notes	258.7		290.1		325.9	345.3		387.6		435		488.3	517.4
Black notes		274.1		307.6			365.8		410.6		460.9		
White and Black Piano Keys													

FIG. 306. — The tempered scale.

395. Tempered scale. If the scale on the piano were made perfect for the key of C, it could not be used for the other keys.

By sacrificing the perfect intervals for one key and making the intervals between any two adjacent tones the same throughout the entire keyboard, it is possible to use music written in any key. The imperfection in musical quality introduced by this device is small, and is not observed by the ordinary person.

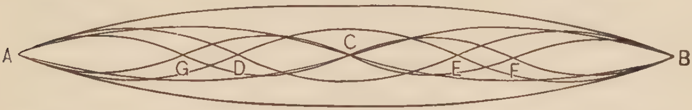


FIG. 307. — The wire *AB* sounds its fundamental when vibrating its full length; its first overtone when its halves *AC* and *CB* vibrate; its second overtone when thirds, *AD*, *DE*, and *EB* vibrate; and its third overtone when it vibrates in quarters, *AG*, *GC*, *CF*, and *FB*.

396. Vibration of strings. The sound derived from vibrating strings varies in quality and pitch. The material largely determines the quality, but pitch depends upon *thickness*, *length*, and *tension*. The bass strings of the piano are coarse and long, the high-pitch strings are fine and short. The tension on the strings may be changed. The process of tuning a piano consists in changing the tension of each wire until it gives a note in unison with some standard. The pitch of a string is doubled by having its length halved. A string may vibrate in parts while it is vibrating as a whole. The tone produced by vibrating as a whole is the **fundamental tone. Overtones** result from the vibration of parts of the string.

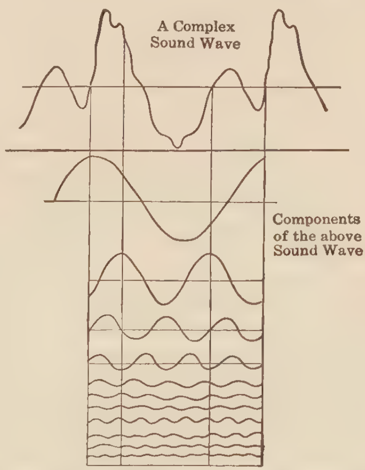


FIG. 308. — The richness of quality of the complex sound is due to the many overtones which blend with the fundamental.

397. The piano. In the back of the upright piano, or under the lid of the grand piano, are found the piano frame and *sounding board*. Here the wires are strung. Each key of the keyboard controls a felt-covered *hammer*. When the key is pressed down quickly, the hammer, by means of connecting levers, strikes a blow on the wire. When the key is released the felt comes in contact with the wire and stops its vibration. The hammers and dampers are also under control of the foot pedals. The loud pedal removes the dampers, thus allowing the strings to vibrate freely. The soft pedal shortens the stroke of the hammers, with the result that a gentler blow is struck. Since repeated blows and changes of temperature tend to loosen the wires, frequent tuning is necessary. The piano should be subject to as little extreme heat or cold and as little rough usage as possible. If a string be struck at a point one-fifth of its length from one end, it will give out a maximum number of overtones. The hammer is so placed in the piano as to produce this pleasing effect. In an upright piano the sounding board at the back of the wires throws the sound forward, but in the grand piano, with its sounding board horizontally beneath the wires, the cover must be raised and supported at an angle of about 45 degrees to reflect the sound when the full volume of sound is desired

398. The piano player. The motive power of the piano player is air. A bellows, which may be operated by foot pedals or by electric motors, produces a vacuum against which atmospheric pressure can operate the keys. A perforated music roll passes over the *tracker bar*, which has an opening in it for every note on the piano. From each opening a tube passes to a pouch which has a pinhole connection to the *air chest*. Each air chest is connected to an *air finger* — a small bellows — whose openings are controlled by the valve. Pedaling sucks the air from the air chest and tubes, so that a partial vacuum always exists in the air chest. When a perforation in the music roll passes over an opening in the tracker

bar, air from the room passes through the tube to the pouch and pushes the valve, with the result that the valve discs close the passage from the air finger to the outside air but open the passage to the air chest. As the air in the air finger rushes into the air chest, atmospheric pressure on the outside causes it to collapse. In collapsing, the top part acts as a lever, causing the hammer to strike the piano strings just as striking the piano key with the finger would do. When the hole in the tracker bar is closed by the moving roll, the valve is pushed back by atmospheric pressure, and air enters the air finger, making it ready for the next striking of that note.

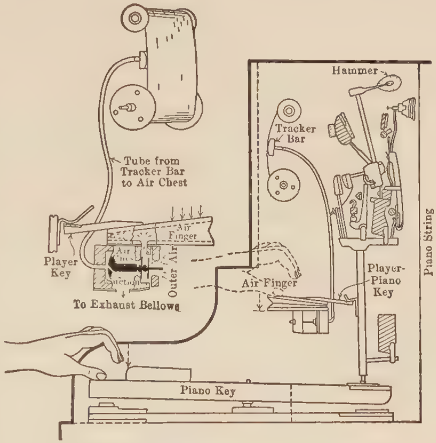


FIG. 309. — Mechanism of the piano and of player attachment.

FIG. 310. — Stringed instruments.

399. Other stringed instruments. In the piano and harp, the length of the string is fixed, and but one note can be produced upon it. In most of our stringed instruments, however, instead of a hundred or more strings, there are but a few: four on the violin and man-

dolin, four on the banjo, and six on the guitar. By shortening these strings it is possible to produce ten to twenty different notes from each of them. The shortening is done by pressing the string against the neck of the instrument, with the fingers of the left hand. The sound is greatly multiplied in all these instruments by forced vibrations and resonance of the sounding box and surfaces. The strings in these instruments are not so well protected as those of the piano, and so need tuning more frequently.

400. Wind instruments. Sounds in wind instruments are produced in three different ways: by *vibrating air columns;* by *vibrating reeds;* by *lip vibration.* The quality of the sound in each case is modified greatly by the form of the instrument. In the ordinary whistle and the organ pipe, a column of air is set into vibration by forcing air across a narrow opening at one end of the pipe. In the breath harp, or *harmonica,* the accordion, and the house organ, many thin metal reeds are so placed that a strong current of air will set them into vibration. The reeds are of different lengths. The short ones have a high pitch and the long ones a low pitch. The clarinet and saxophone have a vibrating reed in the mouth piece. In the horn, bugle, and trombone, the vibrating lips of the player force the air column within the instrument to vibrate.

FIG. 311. — Reed instruments.

401. Vibrating air columns. The length of an organ pipe determines the length of the vibrating air column and in this way determines the pitch of the sound. The shorter the air column, the higher the pitch, other conditions being unchanged. When the end of the organ pipe is open, the tone

is an octave higher than when it is closed. Such instruments as the clarinet and flute have one fixed pipe. Many holes in this pipe are closed by keys, and may be opened by pressure of the fingers. When any hole is opened, the resulting note is that

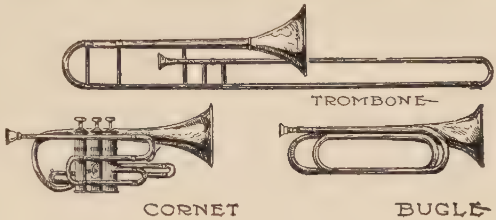


FIG. 312. — Lip vibration instruments.

which would be produced if the pipe were cut off at that point. In the trombone, a sliding extension makes it possible to change the length of the air column. Columns of air may vibrate in segments, just as strings do; thus many

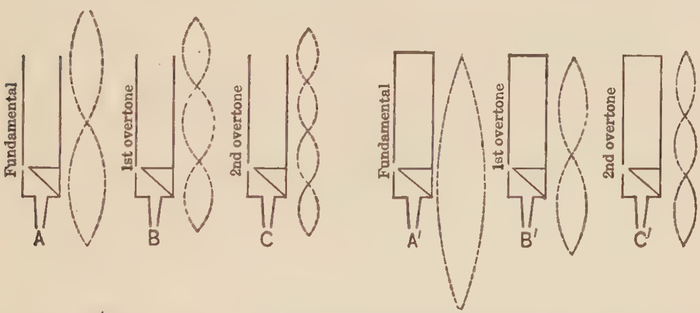


FIG. 313. — Overtones of organ pipe. A, B and C are open. A', B' and C' are closed. The dotted lines represent the sound waves produced in each case.

overtones may be produced with the fundamental of a vibrating air column.

402. The phonograph. The phonograph is one of Thomas A. Edison's inventions. The production of a "record" and the reproduction of the original sound are accomplished by the following method. A person talks, sings, or plays into a horn which has a sensitive disc at the small end. The disc

vibrates to correspond to the sounds produced. This vibratory motion is communicated through a needle to a cylinder or plate of wax, which slowly turns under the needle as the sound is being produced. The needle makes a groove in the wax. This groove is not smooth but wavy. When the vibrating disc is horizontal, the irregularities rise and fall, giving a groove known as the *hill-and-dale*. When the vibrating disc is vertical the irregularities are sidewise and produce a *lateral* groove. In another method the needle of the vertical disc may trace a lateral line on a greased metal disc. By acid etching and electrotyping, a master record is made, from which hundreds of copies can be made on composition materials held in contact with it under pressure. After this record is made, if the needle retraces its path from the beginning, it will be moved exactly as it was when the record was being made; but this time, as it follows the contour of the groove, it produces vibrations in the disc. The disc is thus made to vibrate in just the same manner as it did at first, but now it creates sound waves in the air which may be communicated to the ear. The disc in the reproducer must be in a vertical position for the lateral records and in a horizontal position for the hill-and-dale records.

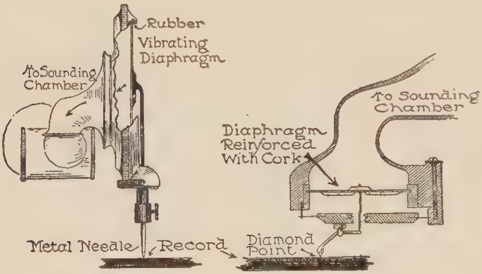


FIG. 314. — The phonograph.

403. How we speak. In our vocal cords and other speech accessories, we have a mechanism capable of the most varied sounds, from harsh noise to the softest music. Few people train themselves in right voice usage, or are even aware of the possibilities which lie dormant in the human voice. Situated in the throat where " Adam's apple " is found, is the *larynx*.

Within the larynx is the *voice box.* In this are two *membranous cords* which are attached to the side walls and partly close the opening, leaving a narrow slit across the middle. By muscular action the slit between the two edges of the cords may be changed. As air is forced through this slit the cords are set into sound-producing vibration.

404. The voice. The human voice, which is the result of the action just described, may be changed at will. The cords may be put under greater or less tension. They may be shortened or lengthened. This variation chiefly affects the pitch of the sound. The mouth and nose cavities act as resonators, and the position of the tongue also modifies the quality of the sound. In our ordinary conversation, we are unconscious of the pitch or quality of our voices, because the act of speaking has become reflex through long custom. The vocal cords, as a rule, are larger in man than in woman. This accounts for the lower pitch in the voices of most men. The character of the vocal cords determines whether their possessor will make a bass, tenor, or soprano singer. The range of the human voice ordinarily is about two octaves, but by training, it can be increased somewhat. The range of the musical voice is from about 64 vibrations (low bass) to 1040 vibrations (high soprano). Children, particularly boys, undergo "a change of voice," during which the voice changes from one of high pitch to one of low pitch. This is due to the rapid growth of the vocal cords which occurs at that time.

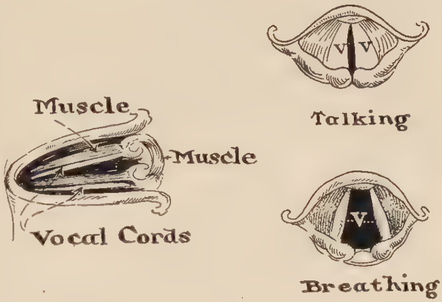


FIG. 315. — The vocal cords.

405. How we hear. When a sound wave comes to the ear, it enters the external ear passage and continues until it meets

the membrane of the eardrum, separating the internal and external air passages of the ear. The air pressure on both sides of the membrane is equalized by an open air passage (Eustachian tube) which connects the middle ear to the mouth. Three small bones in the middle ear communicate the vibrations received by the membrane to the fluids contained in the cochlea of the inner ear. In this chamber are 3000 minute fibers, each of which is capable of vibrating at a certain frequency. Disturbances in these fibers, in which are the ends of the auditory nerve, are transmitted to the brain as nerve impulses, and the sensation of hearing is the result.

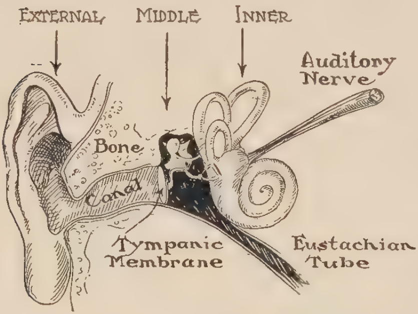


FIG. 316. — Section of the ear.

Just as there are ether vibrations too slow and others too rapid to affect our sight, so there are vibrations in matter with frequency too low, and others with frequency too high, to affect our hearing. The range of the human ear is about ten octaves.

SUMMARY

1. Sound is the result of vibration in matter, of frequencies which are detected by the auditory nerves.

2. Sound travels in waves through matter. Sound waves consist of alternate condensations and rarefactions. The denser the matter, the faster the sound waves travel in it. An echo is a reflected sound which is distinct from the original.

3. The greater the amplitude of vibration, the louder the sound. Loudness decreases with the distance from the source. Forced vibration in a larger surface increases the loudness.

4. A vibrating body is able to set another body of the same frequency into vibration. Vibrations caused in this manner are called sympathetic vibrations.

5. Two waves may unite in opposite phase to neutralize each other, or in like phase to reinforce the sound. Beats result when two bodies of nearly the same vibration numbers are sounding together.

6. Musical sounds vary in pitch, which depends upon the frequencies.

7. Musical sounds are those which are pleasing to the ear, while noise is an unpleasant combination of sounds.

8. A major chord consists of any three notes having the ratio 4 : 5 : 6. A series of these chords gives the notes used in the diatonic scale. By varying the vibration rate of each note in this scale a small amount, in order to make the intervals between two adjacent notes equal, the tempered scale is produced. Music in any key can be played on the tempered scale.

9. The pitch of a vibrating string depends upon the thickness, length, and tension. Shortening a string raises the pitch. When the whole string vibrates it produces its fundamental note. When it vibrates in parts it produces overtones.

10. The piano has many wires of varying sizes. Striking a key causes a hammer to strike a particular wire, at such a point as to produce the maximum number of overtones.

11. The piano player consists of a bellows for producing a vacuum in an "air finger," so that atmospheric pressure may push the key down and make the hammer strike the string. Each key, through an air finger, is under the control of the stops and openings in a sheet of paper (music roll) which passes over a tracker bar connected by pipes to the vacuum chamber.

12. Many of our stringed instruments have only a few strings, but, by fingering, each string is made to produce many different notes.

13. There are three types of wind instruments, producing sound by three methods, viz.: vibrating air columns, as in the organ pipe and whistle; vibrating reeds, as in the harmonica and house organ; and lip vibrations, as in the cornet and bugle.

14. A phonograph record is made by producing the sound before a disc, whose vibrations are recorded in soft wax from which duplicate records can be made. A finished record, placed under the needle attached to another disc, causes vibration in the disc and thus reproduces the original sound.

15. The human voice results from the vibration of vocal cords attached to the walls of the voice box in the larynx.

16. When a sound wave meets the ear membrane, it makes it vibrate. This vibration is carried through the middle ear, by three small bones, to the inner ear, which transmits the sensation to the brain.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. Measuring distance by means of sound.
2. Major and minor chords.
3. A study of pitch from experiments upon some stringed instrument.
4. Prevention of echo in large auditoriums.

REFERENCE BOOKS

BUTLER. *Household Physics.* Whitcomb and Barrows.

FLEMING. *Waves and Ripples in Water, Air, and Ether.* The Sheldon Press. (Macmillan.)

HENDERSON. *Physics in Everyday Life.* Lyons and Carnahan.

HOADLEY. *Essentials of Physics.* American Book Company.

HODGDON. *Elementary General Science.* Hinds, Hayden, Eldredge and Company.

CHAPTER XXV

RADIO

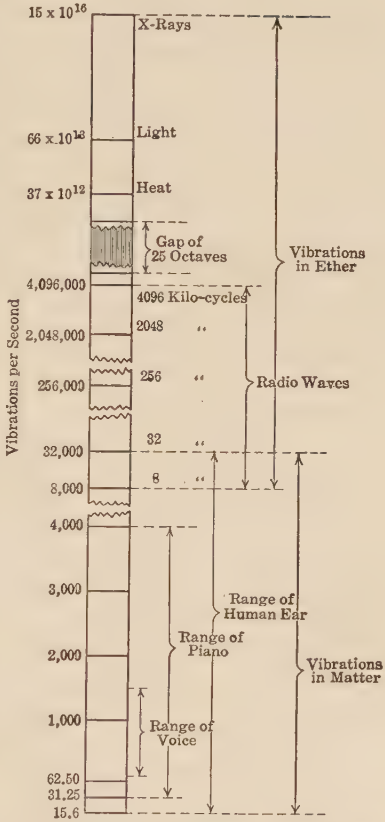


FIG. 317. — Vibrations in matter and in ether.

406. Sound waves and radio waves. Sound waves are vibrations in matter. Radio waves are vibrations in the ether. Our ears are constantly picking up sound waves which pass through the air surrounding us. Radio waves from some source or other are constantly passing by us — even through us, for our bodies, our houses, and almost all materials are transparent to them; and yet we cannot detect them by any of our senses. There are devices which will change the electromagnetic ether waves, which we call radio waves, into sound waves, and so make us aware of their presence and also give us the message which they bring. Among the most marvelous achievements of science are those which make it possible to change the sound of a person's voice

into electrical waves which traverse the ether at a speed of 186,000 miles per second and, at a distance of thousands of miles from the speaker, to have these electrical waves received and changed back into speech so like the original that the voice can be recognized.

407. How wireless was developed. Whenever an electric spark is produced, as may be done by discharging a condenser, the electricity surges back and forth, diminishing at each reversal. This fact was discovered in 1842 by Joseph Henry. The number of oscillations in a single second may be a few thousand or several million. The sparks of a static machine or induction coil which has condensers, also are oscillatory, and it is now known that they set up electromagnetic waves in the ether. Maxwell developed a theory that such waves existed, but not until 1888 were electromagnetic waves in the ether actually detected. Marconi learned of these experiments, which proved that electromagnetic waves would pass through the ether and could be detected, when he was only eighteen years of age. He at once resolved to make use of this wonderful way of carrying energy through space, for the purpose of communicating between places widely separated. In 1894, Marconi had produced the first practical radio detector, called a **coherer,** and from then on he made rapid strides until 1896, when the first public demonstration of wireless was made.

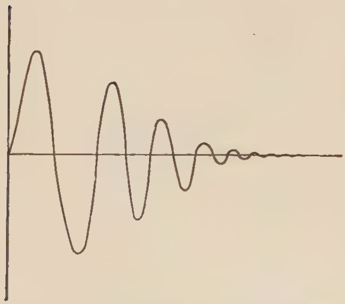


FIG. 318. — Oscillating discharge of an electric spark.

408. Resonance in sound. If a tuning fork having a frequency of 256 vibrations per second is made to vibrate, and is held near another fork whose vibration rate is 256 times per second, this second fork will vibrate and can be heard after

the first fork is stopped. This is a case of resonance or sympathetic vibrations, explained in the preceding chapter. The same thing happens when two steel wires of the same diameter are stretched between two supports. If they are under the same tension and we cause one wire, which is just 100 centimeters long, to vibrate, it will send out waves which are characteristic of these conditions and will set the second wire into vibration. If we try other similar wires all having the same conditions except length, we shall find that only one length of the second wire will respond to vibrations in the first. If our second wire is 110 centimeters, 105 centimeters, or 90 centimeters, it will not be set into vibration when the first one vibrates, but if it is just 100 centimeters we find it will produce sound. Changing the conditions of the second or receiving wire, to produce resonance, may be considered a *tuning* process. Thus, energy sent out by one body may be picked up, in part at least, by a second body, through a process of resonance.

409. Electrical resonance. We can demonstrate electrical resonance by means of two similar condensers, one of which has a varying circuit. One condenser, such as a Leyden jar, has joined to the outside coating a metal conductor whose other end is separated by a small gap from the knob G which joins the inside coating. This we shall call the *wave-producing* equipment; A in Fig. 319. The Leyden jar, A, may be given an electric charge by joining the two surfaces to the two terminals of a static machine or to the secondary coil of an induction coil. Another condenser of the same capacity (B) is fitted with a metal conductor and has a spark gap at the knob (G'). This we shall call the *receiving* equipment; B in Fig. 319. The metal circuit is longer than that

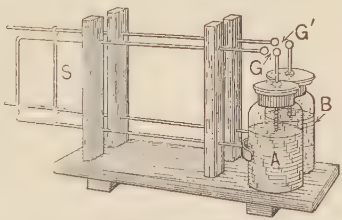


Fig. 319. — Electrical resonance.

in the wave-producing equipment but has a cross sliding wire so arranged that the length of this circuit may be adjusted. When the condenser A is charged and a spark crosses the gap G, the oscillating discharge sends out waves in all directions. Tests are made with B by sliding S into various positions. Only when the circuit is in tune, that is, of the same resistance and inductance, will it pick up the wave. When it is in tune, at every wave sent out by a spark in A's circuit, a tiny spark will appear in the spark gap in the receiving circuit. The spark in the receiving equipment is due to electrical resonance, and you can readily understand how closely it corresponds to sound resonance, previously described. It is evident that, when an electric spark is produced, the electrical oscillations pass through the ether and will be absorbed by another circuit in tune with it, in sufficient amount to make the energy manifest.

410. Radio transmission. The purpose of the sending equipment is to transform sound into equivalent electro-

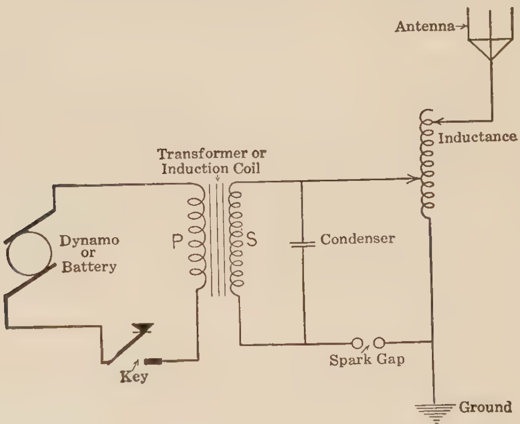


FIG. 320. — A simple spark transmission hook-up

magnetic waves and send them along toward the receiving station. An electric circuit is established from the ground,

through various pieces of sending apparatus, to the *antenna*, in order to produce a large disturbance in the ether. In Fig. 320 a simple spark-sending equipment is shown. A generator furnishes the current, which is stepped-up by a transformer. In the secondary is a condenser and spark gap in parallel. The inductance is for use in tuning to the right wave length. When the key in the primary circuit is closed, a spark passes and the ether wave is started on its journey. By means of intermittent waves, as when code is sent, messages are transmitted. In the set shown in Fig. 320 and in the amateur's

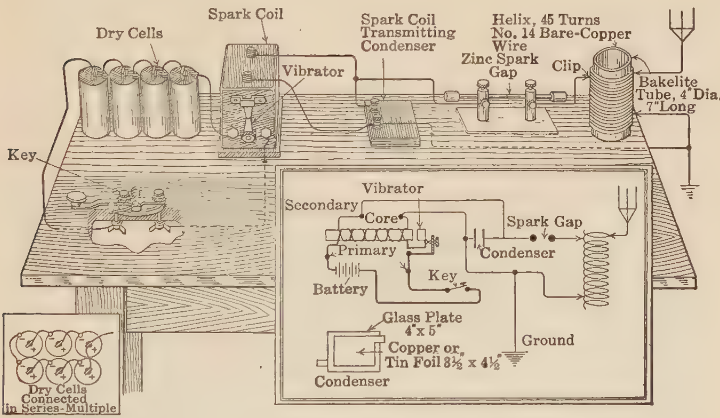


FIG. 321. — An amateur's transmitting radio set.

set, Fig. 321, a spark gap is used for making signals. In many modern sets, a tube-transmitting device is used instead of the spark.

411. Radio reception. Ether waves will be received by receiving devices that are in tune with the transmitting apparatus by which the waves were sent out. By tuning to get the right length of wire at the coupler into the aerial-ground circuit, the electric oscillations will be picked up. (See Fig. 322.) This wave or current is alternating, and so induces a similar current in the secondary; but in order to cause the

telephone receiver to produce sound, this alternating current must be rectified. This is done by the detector, which allows current to flow only in one direction. In the diagram a crystal detector is indicated, but the more sensitive bulb detectors accomplish the same purpose. Each wave, representing a dot or a dash of the code, will make a sound in the receiver, and by this means the message is read.

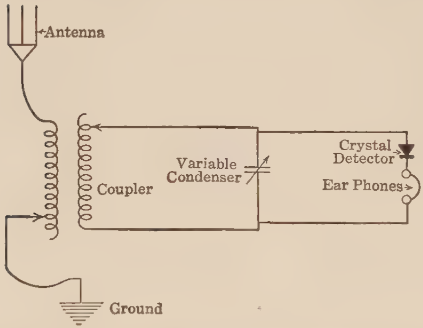


Fig. 322. — A simple crystal receiving hook-up.

Fig. 323. — A corner of the studio of WEAF. Observe the sound-absorbing draperies on walls and the microphone in center.

412. The radio telephone. The sending of speech and music by radio is more difficult than the sending of signals.

In place of the key and induction coil used in the wireless telegraph, a microphone transmitter is used. This has high-frequency current (C W or continuous waves) passing through it all the time. When sound is produced near this transmitter, it changes the resistance, just as it does in the ordinary telephone transmitter. As a result, every sound modifies the amplitude of the electrical waves. When there is no sound, the continuous waves (carrier waves) pass off through the ether and may be received by any appropriate receiver. When a person speaks, or other sounds are made, before the microphone transmitter, modulated waves pass off into the ether and will then be received by anyone whose set is tuned in. In the receiving set, the modulated waves are intensified by means of an amplifying unit and are rectified by a detector. Then the rectified pulsations set up vibrations in the phone-receiver diaphragm, and this reproduces the sounds which, at the sending station, modulate the continuous waves in the microphone.

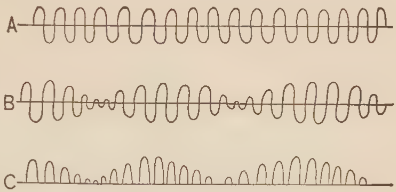


FIG. 324. — *a.* Continuous waves (carrier waves) produced in broadcasting sending apparatus. *b.* Modulated carrier waves. *c.* Modulated waves rectified by the detector.

413. Radio detectors. Detectors are devices which permit electricity to flow in one direction only. When the wave from the receiving aerial reaches the detector, all that part of the wave in one direction is stopped and all that in the opposite direction passes through. The wave which passes through is made up of impulses of direct current and is called the *rectified wave.* It is this rectified electric current that reproduces sound in the telephone receiver. We have already mentioned the crystal detector. It is commonly used for short distance reception. Many kinds of crystals, when joined in a circuit with one wire loosely touching them, allow current to pass in

one direction only. One of the best crystals is galena. The end of a very fine adjustable wire touches the galena loosely, thus closing the detector circuit between the antenna and ground in circuit with the tuning device and the ear phones. The vacuum-tube detector is another device which is very much superior to the crystal detector, since it enables us to hear over greater distances.

414. The vacuum-tube detector. The vacuum-tube detector was used by the Marconi Company of England, in 1902. In 1906, Lee de Forest, of New York, made an improved tube which contained a *grid element.* Further development of the tube was slow, largely because of patent complications. During the World War the patent difficulties were straightened out and since then there has been rapid development of the tube, which is now considered an essential to long-distance radio telephony. The vacuum bulb contains a filament like that in an incandescent lamp, a grid, and a metal plate. The metal plate is outside the filament, and between the filament and the plate is the grid. These bulbs are made to take a 6-volt current to light the filament, or $1\frac{1}{2}$ volts for the small tubes. The battery for lighting the filament is the A battery, and that for charging the plate is the B battery. The grid is charged by connection to the secondary circuit of the transformer and receives an oscillating charge. The plate is connected to the positive pole of a battery, usually giving $22\frac{1}{2}$ to 45 volts.

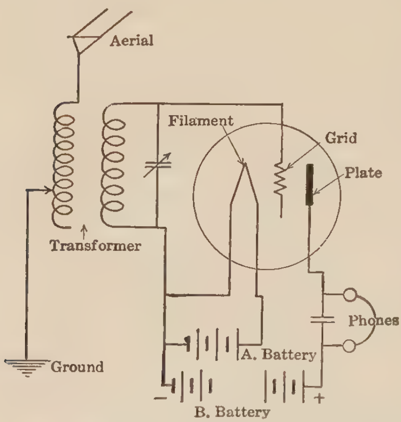


FIG. 325.—A simple hook-up with vacuum tube detector.

415. Theory of action in a vacuum-tube detector. When a vacuum-tube detector is used, the antenna-ground circuit is made through the primary of a transformer. One end of the tube filament is joined to one end of the secondary of this coil. Thus, whatever oscillating or alternating current is picked up by the antenna is reproduced in the filament. The plate is joined to the positive pole of a battery, so that it has a constant positive charge. When the filament of the tube is glowing hot, it sends out electrons or negative electricity. The rarefied gas in the tube under these conditions becomes

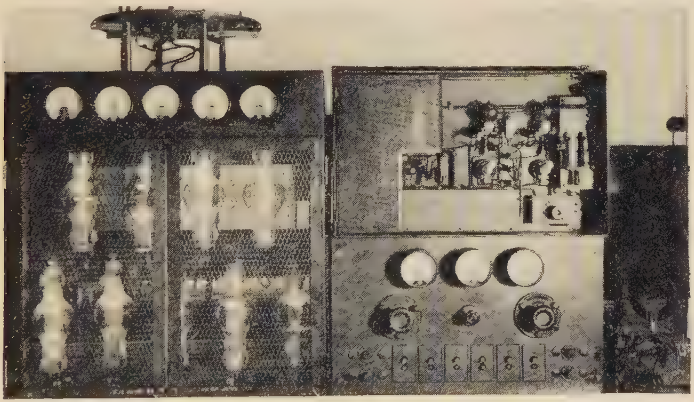


FIG. 326. — Instruments used in KDKA broadcasting station.

conductive, and during the negative phase of current received from the antenna a current of electricity passes across the gap between the filament and the plate. During the time that the positive phase of the alternating current is passing through the filament, there is no passage of current across the gap. Electrons can pass in one direction through the tube, but not in the opposite direction. Thus the tube, which receives an alternating current, passes on only a direct current. This direct current operates the diaphragm of the telephone receiver. The purpose of the grid is to retard or accelerate the flow of electrons between the filament and plate. This is

done by having the grid connected to one end of the secondary, so that it alternately becomes positive and negative, the degree of change being regulated by the grid condenser.

416. Frequency and wave length. The velocity of radio waves in ether is approximately 300,000,000 meters per second. This velocity is the product of the wave length and the number of vibrations per second. Frequency means the number of vibrations per second. Thus, a wave of 100 meters must have a frequency of 3,000,000, and a wave of 3000 meters must have a frequency of 100,000. These figures are so large that a new frequency unit, the *kilocycle*, has been adopted. "Kilo" means a thousand, and "cycle" means one complete alternation. Kilocycle then indicates the number of thousands of times that the wave alternates in the antenna in one second. The frequency 3,000,000 is equivalent to 3000 kilocycles, and 100,000 to 100 kilocycles. Wave lengths used in radio vary from 30 meters to 30,000 meters in length, or from 10,000 to 10 kilocycles. The band of 150 to 200 meters for amateurs is a frequency band from 2000 to 1500 kilocycles.

417. Inductance and capacity. When a current flows through a short straight wire, there is no inductance of importance. When a current flows through a coiled wire, a new current, opposite in direction, is induced at each starting and at each stopping of the current. This induced current opposes the primary current. The inductance increases with the number of turns of wire. If a non-induction coil is desired, the wire can be folded in the middle and the double wire wound upon a central core. Then the induction effect of one half of the wire just neutralizes that of the other half, and no inductance will result. The slide tuning coils and the loose-coupler are *inductance coils*.

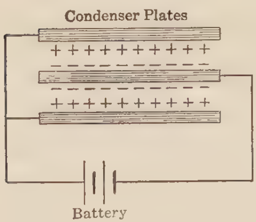
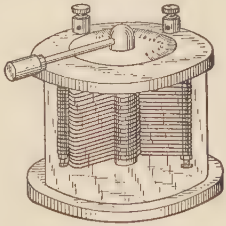


FIG. 327. — Charged condenser plates.

A *condenser* is made up of metallic plates separated by a small gap filled with glass, mica, air, or some other insulating material. These plates provide a place for holding opposite electric charges. The capacity of the condenser is increased by making the plates larger, by using more plates, and by making the gap between them smaller. In an alternating-current circuit, one plate has a positive and the other a negative charge for one instant, but the following instant the charges are reversed.

418. The principle of tuning. Two violinists, about to play together, will "tune up," that is, adjust the tension of the strings so that the corresponding strings have the same vibration rates and so give the same pitch. If a string having a vibration frequency of 256 is sounded, the string on the other violin which, by shortening, by tension, or in some other way, has acquired the ability to vibrate 256 times per second, will vibrate faintly, owing to the resonance previously explained. If such a string is placed near an orchestra or band which is playing, it will respond to the sounds due to 256 vibrations per second and to no others. In a somewhat similar way, tuning is possible in radio. An electromagnetic wave of 300 meters has a frequency of 1000 kilocycles. A receiving antenna circuit may be tuned to receive that particular wave frequency and wave length. In other words, the electrical length of an antenna can be changed by use of condensers and inductance so that one particular wave frequency is received by it better than any other wave frequency. There are various ways of changing the capacity of an antenna so that it will receive the waves desired. A coil of wire joined to the antenna increases its length; two coils, one turning within the other, as in the variometer, change the inductance; a variable condenser



Rotary Variable Type

FIG. 328. — Variable condenser

consisting of two metal plates near, but not touching, each other will also change the electrical length of the circuit.

419. Amplification. Two methods of amplification are in common use. Either may be used alone or both may be used together. These types are called *radio-frequency* and *audio-frequency* amplification. As a rule, when only one is used it is the audio-frequency. In radio-frequency amplification a specially designed transformer is used to step-up the incoming radio wave before it goes to the detector. An amplifying bulb is also used. In audio-frequency amplification a transformer with closed core made of laminated iron is used. The secondary coil has to have nine times as many turns as the primary. This increases the voltage on the grid. The amplifying tubes are similar to the detector tubes but have a higher vacuum. Four stages of either radio-frequency or audio-frequency are likely to produce disagreeable howling, but a combination of two radio-frequency and two audio-frequency stages will give the equivalent four stages of amplification without the disagreeable noise.

420. Receivers. The ear phones used in radio telephone reception have higher resistance than those used for regular telephone service. Those used only for code reception may have diaphragms made more sensitive to vibrations near "high C," which is the usual pitch of the spark telegraph code. This is not a satisfactory phone, however, for radio telephone reception. A diaphragm which responds equally to all pitches will give less distortion. A delicate mica diaphragm, having a small armature at its center, has certain advantages over the all-iron diaphragm.

421. Loud speakers. The receivers may be connected to a horn, to make it possible for several people to hear, but this is not very practicable. The diaphragm cannot vibrate through sufficient amplitude to make a very loud sound, without hitting the magnet and making a rattling sound. There are loud speakers capable of filling a large hall with

sound. About the top of one that uses a 6-volt current for energizing the magnet, is a moving coil which is attached to the diaphragm, Fig. 329. Current from the set comes to the moving coil, and by action which results between these two magnetic circuits the diaphragm is set vibrating.

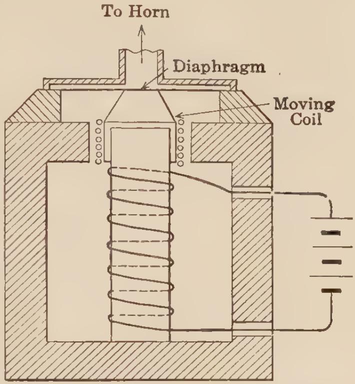


FIG. 329. — Mechanism of a powerful loud speaker.

422. Lightning protectors. The danger from lightning varies somewhat, but the law requires a lightning arrester on all antennae, whatever may be their height. One who is installing a radio set should consult the regulations of the Fire Underwriters and follow them carefully.

SUMMARY

1. Radio waves are ether vibrations. Sound waves can be changed into equivalent ether waves, which can be changed back into sound.

2. There is a close analogy between the behavior of sound waves and that of the ether waves of radio. Both are oscillatory, both produce resonance in bodies capable of similar vibration, and both may be detected by means of such bodies.

3. In wireless telegraphy, a spark produced in a high-tension circuit sends out waves which are detected by suitable equipment properly tuned.

4. In the radio telephone, sound waves change the resistance in a microphone transmitter. Continuous high-frequency waves, which are passing all the time, are in this way modified. The resulting modulated waves travel through the ether. In the receiving apparatus, the modulated waves are

rectified so that they will act on a telephone receiver, by which the sound is reproduced.

5. Crystal detectors and vacuum-bulb detectors permit current to flow only in one direction. Because of this property they are able to rectify the incoming electrica waves, so that they will set up vibration in a telephone receiver.

6. The vacuum-bulb detector has a filament surrounded by a grid, and a metal plate outside the grid. When the filament is lighted and the plate given a positive charge, negative charges from the antenna cause electrons to flow from the filament to the plate. No electrons can flow in the opposite direction. This gives a rectified current to the phone receiver. The grid is a device for regulating the electron flow.

7. Wave length is usually given in meters and frequency in kilocycles. A kilocycle is the number of thousands of times a wave alternates in a second. The velocity of radio waves is 300,000,000 meters per second.

8. At the starting and stopping of a current in a coiled wire, opposing currents are induced. The amount of this inductance depends upon the number of turns in the coil.

9. A condenser consists of two or more conductors separated by insulators. The larger the plates or the more of them, the greater the capacity.

10. In sound, one string is in tune with another which has the same vibration frequency. In a similar way, one electric circuit is in tune with another when it is capable of receiving radio waves of the same frequency, which another circuit sends out. Tuning a receiving set consists in adjusting the different devices so as to produce electrical resonance.

11. Amplification is accomplished by stepping-up the radio wave either before or after it goes to the detector. When done before detection, it is called radio-frequency amplification. If done after the wave has passed the detector, it is audio-frequency amplification. Amplification bulbs have a higher vacuum than detector bulbs.

12. Radio phone receivers have higher resistance than ordinary telephone receivers.

13. Loud speakers are devices for producing greater loudness by giving the diaphragm greater amplitude of vibration.

14. A lightning arrester is required by law for all installations.

SUGGESTIONS FOR FURTHER STUDY: TOPICS, PROJECTS, AND EXPERIMENTS

1. International radio service.
2. Government control of radio transmission.
3. A home-made radio receiving set.
4. Radio broadcasting.
5. Motion picture. *Wizardry or Wireless.* (Film No. 40.) Two reels. General Electric Company.

REFERENCE BOOKS

Collins. *The Book of Wireless.* D. Appleton and Company.

Lescarboura. *Radio for Everybody.* Munn and Company.

Mills. *Letters of a Radio Engineer to His Son.* Harcourt, Brace and Company.

Morgan. *Wireless Telegraph and Telephoning.* Henley Publishing Company.

INDEX

Note: Numbers in heavy faced type refer to pages containing illustrations as well as descriptive text.

A

B

C

D

Electricity

Electro static = stationary

Electro dynamic = moving

glass rubbed with silk = positive charge

rubber + flannel = negative charge.

unlike charges attract each other

Like charges repulse each other

magnetic field

Heat demagnetizes

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last 2 chap

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